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Child Stunting in Madagascar and Zambia: An Examination of Maternal and Child Characteristics, Household Water/Sanitation, and Armed Conflict Exposures

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Child Stunting in Madagascar and Zambia: An Examination of Maternal and Child Characteristics, Household Water/Sanitation, and Armed Conflict Exposures

A dissertation submitted in partial satisfaction

of the requirements for the degree of

Doctor of Philosophy in Public Health

by

Stephanie Ly

2019

ABSTRACT OF THE DISSERTATION

Child Stunting in Madagascar and Zambia: An Examination of Maternal and Child Characteristics, Household Water/Sanitation, and Armed Conflict Exposures

by

Stephanie Ly

Doctor of Philosophy in Public Health

University of California, Los Angeles, 2019

Professor Ondine von Ehrenstein, Chair

Child stunting, or linear growth faltering, affects 1 in 5 children under the age of five years. These 151 million stunted children predominantly live in low- and middle-income countries. For decades, clinicians and researchers considered stunting a form of chronic malnutrition but modest gains were made in eliminating stunting through nutritional interventions. This dissertation explored emerging areas in child stunting. Chapters 1 and 2 introduced stunting and provided backgrounds, respectively. The research was guided by the Social Ecological Model and Life Course Perspective in approaching stunting as embedded in macro structures at multiple levels over the life course of women and children. Chapter 3 described theoretical frameworks and an integrated model.

The analyses focused on Madagascar and Zambia, which were ranked among countries with the highest proportions of child stunting. We used health data from the Demographic and Health Surveys (DHS) and armed conflict data from the Armed Conflict Location and Event

Data Project (ACLED) database in Madagascar and Zambia. Chapter 4 detailed the methodology, including multivariate logistic and linear regression models assessing child stunting and height-for-age z-score (HAZ) outcomes.

Chapter 5 examined maternal anthropometry and child gender factors. Results indicated that short stature or underweight in mothers were associated with increased stunting odds while higher maternal height and BMI scores were associated with higher child HAZ. Chapter 6 investigated household water and sanitation measures. We found that households without piped water and finished flooring were associated with increased stunting odds. Stunting was associated with lack of an advanced flush toilet in Zambia but not in Madagascar. Chapter 7 explored proximity of armed conflict events during critical developmental periods with child stunting and height. Conflict exposure during pregnancy was associated with increased stunting odds and lower HAZ in Madagascar but decreased odds and higher HAZ in Zambia.

This dissertation framed stunting as occurring over the life course and embedded in multiple external structures. These studies were among the first to examine population-level environmental enteric dysfunction risk factors and apply disaggregated conflict data to stunting. We also contributed stunting context in Madagascar and Zambia, which have been understudied.

The dissertation of Stephanie Ly is approved.

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University of California, Los Angeles

2019

DEDICATION

To my parents, your tireless dedication and unconditional love have made everything possible.

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LIST OF ACRONYMS

ACLED	Armed Conflict Location and Event Database
aOR	Adjusted odds ratio
BMI	Body mass index
CI	Confidence interval
DAG	Directed Acyclic Graph
DHS	Demographic & Health Surveys
EED	Environmental enteric dysfunction
GADM	Global Administrative Areas Database
GIS	Geographic Information System
GNI	Gross National Income
GPS	Global Positioning System
HAZ	Height-for-age z-score
IRB	Institutional Review Board
KM	Kilometers
JMP	Joint Monitoring Programme of WHO/UNICEF
L:M	Lactulose to mannitol ratio test
MDHS	Madagascar Demographic & Health Survey IV
PCA	Principal Component Analysis
RUTF	Ready-to-use therapeutic foods
SD	Standard deviations
SDGs	Sustainable Development Goals
SES	Socioeconomic status

UCDP	Uppsala Conflict Data Program
UNICEF	United Nations International Children’s Emergency Fund
USAID	United States Agency for International Development
WASH	Water, sanitation, and health
WHO	World Health Organization
ZDHS	Zambia Demographic & Health Survey V

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CHAPTER 1: INTRODUCTION

The World Health Organization (WHO), World Bank, and UNICEF estimated that 22.2% of children under five globally, about 151 million in total, were stunted and nearly all stunted children lived in developing economies (UNICEF, WHO and World Bank Group 2018). Stunting is a form of growth impairment where children fall below their height trajectory, measured by WHO growth standards (World Health Organization 2004b). High-income countries observed stunting prevalence at less than 6% of children compared to 26% in low- and middle-income countries (Onis, Blossner and Borghi 2011). Overall, stunting prevalence has declined globally since 1990 but improvements have not been equitable. African and Oceanic regions, specifically, saw little decline in child stunting rates in the past few decades (UNICEF, World Health Organization and World Bank Group 2016). Madagascar, an island country located off of the African continent, had one of the highest rates of child stunting in the world with 50.1% of children under five years stunted (National Institute of Statistics Madagascar and ICF Macro 2010). Zambia, a land-locked country located in Sub-Saharan Africa, also had high rates of stunting with 40.0% of children under five stunted (Central Statistical Office, Ministry of Health Zambia and ICF International 2014). Both countries are located in Sub-Saharan Africa and had high rates of child stunting but differ in geography, economics, and political situations. Comparisons between child stunting factors were made amidst these similarities and differences.

Stunting has negative lifelong consequences for children including poor cognitive ability, underperformance in school, low lifetime earnings, and chronic diseases (Onis, Blossner and Borghi 2011, Onis et al. 2013, Popkin, Richards and Montiero 1996, Walker et al. 2015). Stunting in women is associated with stunting in their children, which is a possible indicator of maternal underdevelopment impacting offspring (Addo et al. 2013). Interestingly, stunting rates differed by gender with females stunted in higher proportions in South Asia and males more stunted than females in Sub-Saharan Africa (Wamani et al. 2007). Studies conducted on stunted Malagasy and Zambian children had not specifically explored maternal height and gender. This dissertation examined child stunting related to maternal stunting and child gender in Aim 1.

For decades, stunting was classified as a form of moderate malnutrition, but nutrition interventions achieved null or modest results in alleviating stunting (André Briend 2015, Dewey and Adu-Afarwuah 2008). Therapies such as ready-to-use foods (RUTFs), micronutrients, exclusive breastfeeding, or specialized diets had inconsistent results in resolving stunting (Best et al. 2011, Dewey and Adu-Afarwuah 2008). Thus, recent investigations led to alternate explanations beyond nutrition for stunting.

One emerging factor was an inflammatory intestinal condition called environmental enteric dysfunction (EED). EED was implicated in poor gut barrier absorption and linear growth stunting due to constant exposure to fecal pathogens (Crane, Jones and Berkley 2015, Keusch et al. 2013). The dysfunction impairs nutrient absorption, which may explain the lack of success in using dietary supplements for stunting (ibid). EED typically resolves itself with proper hygiene, sanitation, and clean water (Prendergast and Humphrey 2015, Schmidt 2014). EED diagnosis and treatment of the condition are difficult, especially in resource-limited settings. Most of the research conducted on EED has been primarily clinical. In Aim 2 of this dissertation, indicators of household sanitation and hygiene were used as a proxy for potential EED risk.

Another unexplored area in child stunting is the role of violent conflicts including war, civil unrest, protest, or other violence (Devakumar et al. 2014, Kimhi et al. 2010). Much of the research on violence has focused on individual-level exposures to intimate partner and domestic violence (WHO, UNODC and UNDP 2014). However, armed conflicts have devastating impacts on political, economic, health, and social wellbeing at the individual and population levels (Devakumar et al. 2014). Psychological trauma in both children and their mothers have long-lasting consequences (Jeharsae et al. 2013). Moreover, the timing of conflicts may differentially affect a child depending on their stage of development (Akresh, Caruso and Thirumurthy 2014, Duque 2017). Armed conflicts have rarely been examined with child stunting, which was explored in Aim 3 of this dissertation using disaggregated conflict data.

Overview of study aims

This dissertation focused on emerging, non-nutritional factors associated with stunting in children using nationally representative data at the household and individual levels in Madagascar and Zambia. The study sample was restricted to children under five years with complete data on height and weight to ascertain stunting status. Child stunting outcome was examined through three research aims:

Aim 1: To determine whether maternal anthropometry was associated with child stunting and height attainment.

1. Investigate whether maternal short stature was associated with child stunting and height attainment.
2. Examine if maternal underweight or overweight were associated with child stunting and height attainment.
3. Compare rates of stunting and height attainment between male and female children.

Aim 2: To examine whether indicators of household sanitation and hygiene were associated with child stunting and height attainment.

1. Identify whether the highest quality toilets were associated with child stunting and height attainment.
2. Investigate whether the highest quality drinking water source was related to child stunting and height attainment.
3. Examine whether the highest quality of household floor materials was associated with child stunting and height attainment.
4. Explore whether other exposures like presence of animals and hygiene behaviors were associated with stunting.

Aim 3: To investigate whether armed conflict exposures among children and their mothers were associated with child stunting and height attainment.

1. Examine whether any conflict exposure and number of conflicts during critical developmental periods (pregnancy and first year of life) were related to increased stunting.
2. Explore whether associations between stunting and conflict differed by type of conflict and distance from household.

This dissertation contributed a quantitative analysis of child stunting using cross-sectional, population-based data in Madagascar and Zambia. Results from this dissertation have implications in understanding emerging stunting factors while contributing to the Malagasy and Zambian context.

This dissertation was organized into eight chapters. Chapter 1, this chapter, was an introduction to stunting and the aims of this dissertation. Chapter 2 provided a detailed background on child stunting, the study sample, and background literature. Chapter 3 applied theoretical frameworks to child stunting and formed the integrated conceptual model guiding the analyses. Chapter 4 detailed the research aims and hypotheses, analytic plans, and statistical models. Chapters 5, 6, and 7 presented the analyses conducted for Aims 1, 2, and 3, respectively. Chapter 8 synthesized findings and provided a global discussion of all aims, limitations, strengths, implications, and conclusions.

CHAPTER 2: BACKGROUND

Stunting

About 22% of all children under five in 2017 were stunted, a form of linear growth faltering, totaling 151 million children globally with the highest prevalence observed in low- and middle-income countries (UNICEF, WHO and World Bank Group 2018). Researchers predicted a continuous decline in stunting, but estimate that 131 million children under five will still remain stunted in 2030 (Galasso et al. 2017). Stunting is diagnosed by assessing a child's length or height, age, and sex to the WHO Global Growth Standards, a multi-ethnic distribution of height-for-age z-scores (HAZ) (World Health Organization 2004b). A child falling two standard deviations or below the median is considered stunted and severely stunted below three standard deviations. Large improvements have been made in recent decades and overall stunting has declined globally since 1990 but these gains have not been equitable. In Sub-Saharan Africa (SSA), stunting affected 35.6% of children in the region, which was higher than the global average of 25.7% of children (Onis et al. 2013).

Stunting can begin *in utero* and persist throughout childhood and adulthood (Prentice et al. 2013). Stunting in children is linked to stunting in their mothers. Short-statured mothers with heights below 145 cm are associated with higher rates of birth complications and increased risk of having stunted children (Stewart et al. 2013). Impaired linear growth is predicted to occur as early as *in utero* with neonates born small for gestational age (Shrimpton et al. 2001). After birth, a particularly vulnerable period for growth faltering can occur between 3 to 24 months of age. After this stage, children's height and growth rate increases at a faster rate until age five (Shrimpton et al. 2001). Child growth and stunting in children under five were examined using two age cut points: 0-23 months and 24-59 months. The critical timeframe to intervene in stunting is in early childhood, before 60 months of age. After this period, stunting is considered irreversible and can lead to adverse lifelong consequences. Researchers emphasize that stunting interventions ideally target the first 1,000 days of life, which includes gestation and the first 24 months of life (World Health Organization 2014). When stunting persists, children evidence cognitive impairment and lower educational performance, which leads to lower lifetime wage earnings (de Onis et al. 2013, Galasso et al. 2017, Walker et al. 2015). Stunted individuals also develop chronic diseases like diabetes and obesity more frequently than non-stunted individuals (Hoffman et al. 2000). Given the global magnitude of stunting and negative lifelong consequences, the need for intervening is urgent.

Stunting rates have differed between male and female children. Previous research had found higher stunting rates among girls in Asia, but conversely found higher rates among boys in Sub-Saharan Africa (Hill and Upchurch 1995, Wamani et al. 2007). A pooled analysis of DHS data from 10 SSA countries documented stunting prevalence at 40% among male and 36% among female children (Wamani et al. 2007). Gender differences in stunting are unclear in etiology and may involve biological, social, and cultural determinants. Maternal height is also highly associated with stunting in children, which introduces other possible explanatory pathways (Hambidge et al. 2012).

Stunting has traditionally been considered a form of chronic malnutrition yet nutritional interventions have resulted in null or modest results (André Briend 2015, Dewey and Adu-Afarwuah 2008). Dietary supplementation, including micronutrients and ready-to-use therapeutic foods (RUTFs) had minimal impact on stunting (André Briend 2015, Marko Kerac et al. 2014). While adequate caloric and nutrient intake are necessary for growth, they do not wholly resolve stunting (Dewey and Mayers 2011). Paradoxically, stunting is found in both adequately nourished and overweight children, which further suggests factors beyond nutritional deficiencies (Popkin, Richards and Montiero 1996, Schmidt 2014). A review of interventions found that combined approaches including complementary feedings, nutritional interventions, and conditional cash transfers effectively reduced stunting (Bhutta et al. 2008).

Stunting has unclear etiologic mechanisms and has been associated with multiple risk factors including low socio-economic status, nutrition, helminth infection, mycotoxin exposure, stress, diarrhea, and poor sanitation (Checkley et al. 2008, Papier et al. 2014, Smith, Stoltzfus and Prendergast 2012, Spears, Ghosh and Cumming 2013, Stammers et al. 2015). These associations were primarily derived from cross-sectional observations. Helminth infections in children were associated with stunting but deworming efforts had little effect on height (Taylor-Robinson et al. 2015). Mycotoxin exposure, particularly aflatoxin, is linked to growth impairment but biological pathways are unclear (Khlangwiset, Shephard and Wu 2011). Stress among children or their mothers has been associated with stunting, including chronic stressors and intimate partner violence (Devakumar et al. 2014). Diarrhea is associated with stunting but is described as the 'tip of the iceberg' and indicative of other systemic gut issues (Prendergast and Humphrey 2015). Poor sanitation, including the absence of toilets and sanitation, has also been implicated in a complex pathway towards stunting. The forefront of current investigations focuses on various non-nutritional explanatory pathways in stunting.

Madagascar

In Madagascar, 50.1% of children under five years of age are stunted and 26.4% are severely stunted, equating to about 1.7 million Malagasy children (National Institute of Statistics

Madagascar and ICF Macro 2010). Madagascar is an island country located in the Indian Ocean off the southeastern African coast with French and Malagasy as the official languages (Central Intelligence Agency 2017b, National Institute of Statistics Madagascar 2014). It is one of the most biodiverse countries with three distinct climates zones and unique animal species (ibid). Madagascar is classified as a low-income economy by the World Bank with GNI (gross national income) per capita at $420 USD (Central Intelligence Agency 2017b, World Bank Group 2017a). In 2014, the total population of Madagascar was 22.4 million people with 64.3% living in rural areas (National Institute of Statistics Madagascar 2014, World Bank Group 2017b). The population structure is young with the median age at 19.5 years and a total fertility rate of 4.0 children (Central Intelligence Agency 2017b). Life expectancy is 63.9 years for males, 67.0 years for females, and 65.5 years for both genders (World Health Organization 2016).

Poverty is rampant in Madagascar with 71.5% of the population living below the poverty line in 2012 (National Institute of Statistics Madagascar 2014). Literacy is low at 64.7% of the population and average school completion is just 11 years for males and 10 years for females (ibid). Overall, Madagascar has low socioeconomic positioning and ranked low on development indicators. The Human Development Index, a comparison of healthy human life and development, ranked Madagascar at 158 out of 188 countries and territories in 2015, which was a global low (United Nations Development Programme 2016).

Public health infrastructure is also lacking in Madagascar. In 2015, only 51.5% of the total population had access to improved drinking water sources and just 12.0% had access to improved sanitation facilities (Central Intelligence Agency 2017b). The highest death and disability risk factors in Madagascar were attributed to: malnutrition, WASH (water, sanitation, and hygiene), air pollution, high blood pressure, and dietary risks (Institute for Health Metrics and Evaluation 2016a).

Complicating low economic, development, and health metrics are contentious political circumstances in Madagascar. Since the country gained independence from France in 1960, Madagascar has struggled with political turmoil including presidential power abuses, protests, and coup d'états (Central Intelligence Agency 2017b). The Malagasy constitution has been reformed, the Senate was dissolved and reinstated, and a non-democratic takeover of presidential powers occurred. In 2009, the sitting president was deposed without a democratic election, which resulted in economic sanctions from international leaders and further unrest (Central Intelligence Agency 2017b). A democratic election and transfer of power occurred in 2014 but political uncertainty has persisted with an attempted impeachment and re-establishment of a previously dissolved Senate in 2015 (BBC World 2017b).

Zambia

In Zambia, 40.1% of children under five years are stunted with 17.2% were severely stunted, totaling about 1.2 million Zambian children (Central Statistical Office, Ministry of Health Zambia and ICF International 2014). Zambia is a landlocked country located in Sub-Saharan Africa with a Protestant Christian religious majority and English as the official language (Central Intelligence Agency 2017a, Central Statistical Office 2013). Zambia is recognized as one of the fastest growing economies although economic growth had stalled due to falling copper exports (Central Statistical Office, Ministry of Health Zambia and ICF International 2014). Zambia is classified as a lower-middle-income economy by the World Bank with GNI (gross national income) per capita at $1,490 USD (Central Intelligence Agency 2017a, World Bank Group 2017a).

In 2011, the total population of Zambia was 13.7 million people with about 60% living in rural areas (Central Statistical Office 2013). The population structure is young with the median age at 16.7 years and a total fertility high at 5.9 children (Central Intelligence Agency 2017a, Central Statistical Office 2013). Life expectancy is 59.0 years for males, 64.7 years for females, and 61.8 years for both genders (World Health Organization 2016).

About 60.5% of the Zambian population live below poverty (Central Intelligence Agency 2017a, Central Statistical Office 2013). Zambia's extreme poverty rate has declined but remained at 42.3% in 2010 (Central Statistical Office 2013). Literacy is low at 63.4% among Zambians aged 15 years and older and just 27.6% completed twelfth grade (Central Intelligence Agency 2017a, Zambia Ministry of Finance 2013). The Human Development Index ranked Zambia low at 139 out of 188 countries and territories (United Nations Development Programme 2016).

Universal public health infrastructure has not yet been achieved in Zambia. In 2015, 65.4% of the total population had access to improved drinking water. Improved sanitation facilities were only available to 43.9% of the population in 2015 (ibid). The highest risk factors leading to death and disability included malnutrition, unsafe sex, air pollution, WASH (water, sanitation, and hygiene), and alcohol and drug use (Institute for Health Metrics and Evaluation 2016b).

Zambia has been more peaceful than its conflict-ridden neighboring countries with no civil wars since its independence from Britain in 1964 (BBC World 2017a). Political unrest and demonstrations occur but have not deteriorated into national warfare. The most notable disturbances were food riots in 1990, an attempted coup in 1997, fighting with Angolan forces in

2000, political oppositions in 2001, food insecurity due to natural disasters in 2001, protests of exploitation by Chinese mining firms in 2007, fatal shootings at a Chinese mine in 2010, demonstrations for secession of western Zambia in 2011, deadly pay protests at Chinese mines in 2012, rioting and looting of Rwandan population in Zambia in 2016, and opposition to current President Edgar Lungu in 2016 and 2017 (BBC World 2017a). These events mark the ongoing economic transition of Zambia.

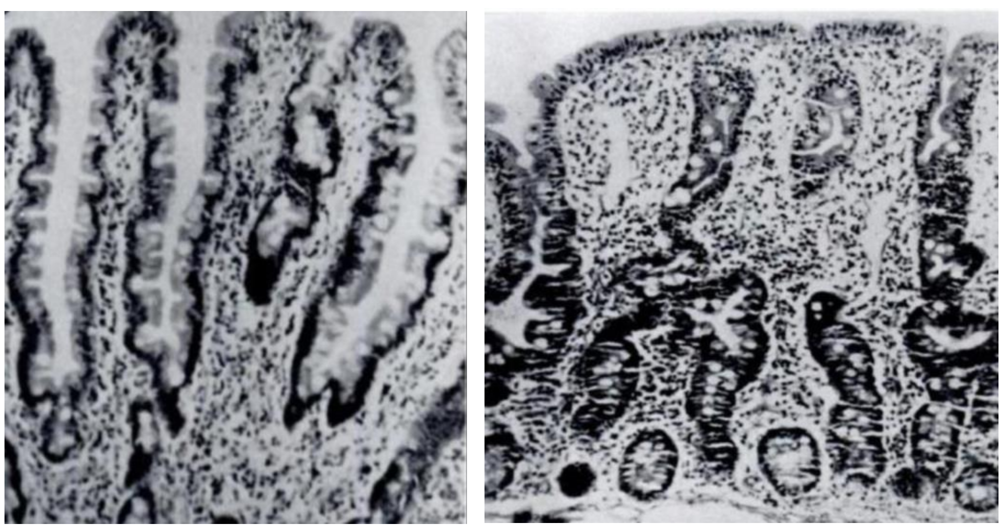
Environmental Enteric Dysfunction (EED)

Environmental enteric dysfunction (EED) is an autoimmune and inflammatory condition, which results in blunted intestinal villi, abnormal epithelia, permeable membranes, and entry of microbes into the small intestine (Guerrant et al. 2013). EED has been implicated in child stunting and is an acquired condition stemming from constant exposure to fecal pathogens. Since the 1960s, clinicians recognized blunted small intestinal villi led to reduced absorption occurring in tropical regions like Costa Rica, Thailand, India, and Pakistan and subsequently termed the condition tropical enteropathy (Baker and Mathan 1968, Keusch et al. 2013).

Researchers examined individuals who migrated between tropical and non-tropical conditions. In one study, Peace Corps volunteers that resided in India and Pakistan would return to the U.S. with gastrointestinal issues that subsided after several months, which suggested an environmental condition (Lindenbaum, Gerson and Kent 1971). Moreover, the same researchers reversed their design and tracked Indian and Pakistani immigrants that relocated to New York City. They found that intestinal issues faced by the immigrants gradually improved, though more slowly than the Peace Corp group (Gerson et al. 1971). These findings were essentially unnoticed until recently.

When researchers determined that the source of intestinal enteropathies was not actually due to tropical climates, but rather lack of sanitation and constant fecal pathogen exposure, tropical enteropathy was renamed environmental enteropathy, and more recently termed environmental enteric dysfunction (EED). EED is described as ‘leaky guts’ with health consequences including reduced intestinal function, increased infection susceptibility, malabsorption of nutrients, decreased oral vaccine efficacy, cognitive and linear growth impairment, increased morbidity, and reduced economic productivity (Dewey and Mayers 2011, Korpe and Petri 2012). Figure 2.1 compares healthy small intestinal features on the left and EED-like characteristics on the right.

Figure 2.1 Normal small intestinal tissue (left) compared to individual with enteric dysfunction (right) (Source: Korpe and Petri 2012)



EED primarily affects the small intestine, which is the main digestive organ, spanning 20 feet with complex surface area to digest food, fight pathogens, and regulate homeostasis (National Institutes of Health 2016). Due to the embeddedness of the intestinal tract, diagnosing conditions like EED are most accurately made by biopsy. However, biopsies are invasive and cumbersome, which led to the use of proxy biomarkers allowing for more practical EED diagnoses in developing countries and among young children. The lactulose to mannitol (L:M) ratio urinary test is the most commonly used biomarker, which tests intestinal dual sugar absorption ability (Crane, Jones and Berkley 2015, Denno et al. 2014). Fecal EED biomarkers included neopterin, calprotectin, lactoferrin, myeloperoxidase, and alpha-1-antitrypsin test intestinal damage and inflammation (Crane, Jones and Berkley 2015, Kosek et al. 2014). Blood biomarkers like zonulin and EndoCAb test malabsorption and intestinal permeability while citrulline tests total enterocyte mass (ibid). Biomarkers and other proxy forms of EED detection methods are still being refined and developed.

A literature review of EED mechanisms show multiple potential pathways for acquiring EED (Crane, Jones and Berkley 2015). Repeated exposures to pathogens through fecal contamination of food or water, lack of toilets, poor hygienic behaviors, and microbial ingestion activates an immune response leading to EED (Dewey and Mayers 2011). Common pathogens include *Cryptosporidium*, amoeba, hookworm, roundworm, *Escherichia coli*, and *Giardia duodenalis* (Crane, Jones and Berkley 2015). Internally, pathogens could create an intestinal microbiome imbalance, small bacterial overgrowth, co-infections, and an autoimmune response (Crane, Jones and Berkley 2015, Korpe and Petri 2012). The immune response pathway specifically activates interleukin-6 cytokines, tumor necrosis factor-a, and C-reactive protein after microbes permeate the gut epithelia (Prendergast and Humphrey 2015). These pathways are believed to onset EED in children at the end of exclusive breastfeeding and initiation of potentially contaminated complementary foods, typically occurring around six months of age (Crane, Jones and Berkley 2015).

EED is posited as a mediator on the larger pathway between nutrition and child stunting. The primary hypothesized mechanism between EED and stunting is through reduced nutrient absorption capacity from shortened small intestinal villi (Korpe and Petri 2012). A secondary pathway could occur through growth hormone axis suppression indirectly caused by the autoimmune response (Prendergast and Humphrey 2015). This is evidenced by lowered levels of insulin-like growth factor 1 (IGF-1) in children with heightened inflammatory markers like cytokines, which suggests an inverse correlated relationship (Prendergast et al. 2014). The biological mechanisms between EED and stunting are complex and had not been completely established, which may result in the discovery of other future factors.

As strides are made to detect and understand EED, treating the condition has been challenging. The forefront of EED studies has been concentrated on clinical trials and community-based interventions through L:M tests and other biomarker improvements (Arnold et al. 2013, Humphrey et al. 2015, Trehan et al. 2015). Some studies targeted a combination of nutritional, sanitation, or behavioral factors while others trialed medication used in similar intestinal autoimmune conditions like celiac disease (Jones et al. 2014, Ryan et al. 2014, Smith et al. 2014, Trehan et al. 2015). Most clinical trials resulted in mixed, modest, or null results in resolving EED or stunting, including recent interventions that addressed nutrition, sanitation, and behavior (Luby et al. 2018, Null et al. 2018, Prendergast et al. 2019). The inconsistent findings in stunting mitigation highlights the complexity and multifactorial nature of the condition. In this dissertation, we contribute one of the first uses of nationally representative data analyzing EED with child stunting. These analyses are also among the first known analyses of child stunting in Madagascar and Zambia.

Hygiene and Sanitation

Recent publications underscore the critical role that hygiene and sanitation play in EED and child stunting (Guerrant et al. 2013, Schmidt 2014). In one multi-country analysis, open defecation accounted for child stunting even after controlling for wealth variables, suggesting the importance of further examining sanitation (Spears 2013). In India, both wealthy and poor children were stunted, likely due to widespread open defecation (Spears, Ghosh and Cumming 2013). Sanitation practices differ by household, region, or country.

The type of toilet facility and drinking water source reported by households is a proxy of possible contamination between sanitation infrastructure and food or water sources, propagating the fecal-oral exposure pathways. The DHS collected respondent answers of toilet type, drinking water source, household construction materials, and hygiene behaviors. The DHS categorized responses into a single pre-determined toilet type, water source, and house material types. We used these responses and classified them using different definitions: 1) binary classification of best sources versus all others (Husseini et al. 2018), 2) Joint Monitoring Programme (JMP) definitions by the WHO and UNICEF, and 3) classifications by epidemiologists (Fink, Gunther and Hill 2011). We detailed these specific classifications in the Appendix.

The household environment also contributes to EED development. Household flooring materials could consist of contaminated soil and increase pathogen risks when children sleep or play on the floor (George et al. 2015a). Ownership of animals and exposure to animal waste near the home are also another source of pathogen exposure. Studies found that young children ingested soil contaminated by chickens, cattle, and other animals (George et al. 2015b). George et al. (2015) found that 97% of study households in rural Bangladesh tested positive for *E. coli* in soil. Similarly, a study conducted in Ethiopia and Zimbabwe observed infants ingesting chicken feces and *E. coli*-contaminated soil (Ngure et al. 2013). Since the DHS did not collect soil samples to test for contamination, self-reported household environment served as proxy measures.

Behavioral factors like proper hygiene practices could prevent microbial ingestion even when with a lack sanitary infrastructure. WASH (Water, Sanitation, and Hygiene) programs target behaviors that transmit diseases through the traditional F-diagram pathways from feces to fingers, fluids, flies, and floors, which could lead to food contamination (World Health Organization 2001). The DHS had limited questions on household hygiene behaviors but did include questions on handwashing, water treatment, and stool disposal.

Although sanitation and hygiene has been implicated in EED and other comorbidities, two recently completed nutrition and WASH trials failed to produce significant improvements in child stunting (Luby et al. 2018, Null et al. 2018, Prendergast et al. 2019). One article explained that this disappointing finding could be due to the definitions of sanitation and water where only the highest standard of sanitation and water sources would reduce child stunting (Husseini et al. 2018). This highest standard of sanitation was defined as a flush toilet and piped water into the household and are detailed in Aim 2.

Maternal Anthropometry

Stunting may be transferred between generations from mothers to their children. Mothers with short stature (height below 145 cm) and/or stunting (height-for-age z-scores at or below -2) tend to have stunted children (Addo et al. 2013, Hambidge et al. 2012, Han et al. 2012). Short maternal height may be partially rooted in genetics, but is also strongly influenced by rampant poverty and malnutrition, which manifests as an intergenerational consequence (Stewart et al. 2013). For example, the Dutch famine cohort found that women exposed to famines as fetuses tended to have shorter infant birth length, which affects health outcomes across three generations (Painter et al. 2008).

Maternal BMI (body mass index) status has unclear associations with child stunting. BMI is calculated using body weight divided by height squared and categorized into nutritional statuses: underweight (BMI < 18.5), normal ($18.5 \leq$ BMI < 25.0), and overweight (BMI ≥ 25.0). One study found that higher maternal BMI led to increased height-for-age z-scores in children (Bhalotra and Rawlings 2011). However, some investigators reasoned that this association was not a causal link but rather an example of the epidemiologic paradox of undernourishment and overweight populations in a country (Dieffenbach and Stein 2012). The role of maternal short stature, height, nutritional status, and BMI score with child stunting and height is explored in Aim 1.

Sex/Gender Differences

In population-based studies of child stunting, sex differences have been observed where boys were found to be more stunted than girls across several countries and regions (Baig-Ansari et al. 2006, Choudhury et al. 2016, Wamani et al. 2007). This unexpected and consistent finding could be rooted in multifactorial mechanisms including genetic, biological, and social structures (Hill and Upchurch 1995, Wells 1999).

Previous systematic reviews and analyses of sex differences in child stunting performed across the Demographic & Health Surveys found that boys were more stunted than girls across countries in Sub-Saharan Africa but not in South Asia (Hill and Upchurch 1995, Wamani et al. 2007). Female infanticide and neglect of female infants has been widely documented and linked to excess mortality and morbidity of girls in China and India (Coale and Banister 1994, Khera et al. 2014, Nayak 2014). In Sub-Saharan Africa, gender discrimination also exists but female child mortality rates do not suggest similar stark health differences (Alkema et al. 2014, Seguino and Were 2013). In countries where child gender inequity was minimal, females fared equal or better than males in early life since males tended to be more prone to early life mortality and had overall lower survival rates (Hill and Upchurch 1995). Female disadvantage, instead, accumulated after the first five years of age (Alkema et al. 2014). Over the life cycle, females survive longer, on average, with longer life expectancy compared to males globally (World Health Organization 2016).

The discrepancy between male and female children is also posited as a biological phenomenon. Beginning in gestation, male fetuses are more negatively impacted by environmental adversities (Arnold et al. 2013, DiPietro and Voegtline 2017). This disadvantage is also evidenced at birth with male neonates born with lower birth weights (Stevenson et al. 2000). A survival bias could occur where females are naturally selected during pregnancy after exposures to maternal environmental stressors like physical harm, toxicants, or lack of nutrients (DiPietro and Voegtline 2017, Wells 1999). Females trended towards survival as compared to male children in early childhood, under 5 years, but after this period, females had notable survival disadvantages in middle-childhood (Hill and Upchurch 1995). On the individual level, these sex differences contribute to sex differentials at the population-level trend.

This dissertation explored child sex differences and associations with maternal height in child stunting. Male children were hypothesized to be stunted in higher proportions than female children, consistent with the literature on Sub-Saharan Africa (Wamani et al. 2007). We explored maternal anthropometric indicators (short stature and BMI) with child gender on stunting in Aim 1 within Chapter 5.

Armed Conflicts

A novel and understudied phenomenon in child linear growth is the role of armed conflicts in their geographic area or country. Conflicts were reported in 37% of countries globally in the past two decades (Devakumar et al. 2014). Armed conflicts affected several dimensions including social, economic, political, and wellbeing. The World Health Organization defines violence as “the instrumental use of violence by people who identify themselves as members of a group – whether this group is transitory or has a more permanent identity – against another group or set of individuals, in order to achieve political, economic, or social objectives” (World Health Organization 2002:15). Armed conflicts could lead to more serious events including warfare, terrorism, genocide, human rights abuses, or other types of organized violent crime (World Health Organization 2002). The literature is sparse on armed conflicts and effects on child stunting with much of the research focused on the negative effects of intimate partner violence (IPV) and child stunting or armed conflicts on child mortality (Kadir, Shenoda and Goldhagen 2019, Rico et al. 2011).

Armed conflicts could involve different actors and situations including civilians, the government, external forces, armed rebellions, and others (ACLED 2017). Conflicts are linked destabilization of regions, exacerbation of already poor economies, decreased health, water and sanitation access (World Health Organization 2002). Conflicts severely impact women and children with women disproportionately affected by rape and sexual violence (World Health Organization 2002). Mothers exposed to armed conflicts experienced adverse health outcomes including physiologic and psychological consequences (Devakumar et al. 2014). Violence during pregnancy was also associated with gynecologic issues, unintended pregnancy, abortions, premature birth, and low birth weight (Campbell 2002, Murphy et al. 2001, World Health

Organization 2002). Children exposed to conflicts are more vulnerable to increased morbidity and mortality through conditions like malnutrition, vaccine-preventable diseases, or infectious diseases (ibid). In addition to physical illness, severe psychological trauma could result regardless of age, and across the lifespan (ibid). Post-traumatic stress disorder (PTSD), anxiety, grief, and other trauma-induced conditions could also occur after conflicts and linger long after (Kimhi et al. 2010).

Stunting has been associated with stress and conflicts in few studies (Akresh, Verwimp and Bundervoet 2011). Children living in high-stress environments exhibit growth failure due to growth hormone suppression (Skuse et al. 1996). Stress levels and post-traumatic growth in children differs by gender with females experiencing higher stress and lower growth, complicating the gender and conflict dynamics (Kimhi et al. 2010). Investigators found that early childhood war exposure was negatively associated to HAZ (Akresh, Lucchetti and Thirumurthy 2012). Similarly, longer-term conflicts and war exposures resulted in lower HAZ and more severe stunting (Minoiu and Shemyakina 2014).

In Madagascar, a peak in conflict reports was found in the year 2002 and 2009 (BBC World 2017b, Raleigh 2016). Contrastingly, Zambia had not experienced the same level of persistent political instability but still had reports of armed conflicts and riots (BBC World 2017a). Both countries had high rates of stunting but diverse types and frequency of conflicts. Despite the prevalence of violent conflicts, child stunting rates could be improved before political stability is met. Nepal reduced child stunting rates from 56.6% to 40.0% of children from 2001 to 2011 despite ongoing social and political turbulence by improving sanitation, increasing household wealth, and enhancing access to preventive health services (Headey and Hoddinott 2015). These interlinked mechanisms with child stunting presents opportunities in developing widescale programs and policies in Madagascar and Zambia to similarly reduce stunting rates.

In this dissertation, we explored different armed conflict exposures during critical developmental time periods and their associations with child stunting. Conflicts were known to affect mothers and children long after an incident with potential lifelong or transgenerational consequences (Devakumar et al. 2014). We examined whether armed conflicts affected child stunting during two time periods: pregnancy and the child's first year of life.

Covariates

Several factors may affect the relationship between our proposed independent variables with child stunting. The most commonly used covariates in previous child stunting literature include household wealth, maternal educational attainment, urban or rural location, birthweight, child age, nutritional intake, birth order, and household size. This dissertation tested a variety of covariates based on this prior literature and included the best fit variables.

Parental and household socioeconomic status is a major determinant for stunting, development, overall health outcomes, future economic attainment, and lifelong trajectories (Fotso and Kuate-Defo 2005, Urke, Bull and Mittelmark 2011, Wagstaff and Watanabe 2003). The Demographic & Health Surveys measured household wealth from locally constructed wealth indices as a composite measure of assets like televisions, bicycles, housing construction, and other items (DHS Program 2017b, Rutstein). DHS wealth quintiles were generated from Principal Component Analysis (PCA) conducted for each country (ibid). Another aspect of socioeconomic status includes maternal educational attainment. The DHS asked women to report the total number of years of schooling and highest educational attainment (primary, secondary, or higher education) (DHS Program 2017b). Maternal and parental educational attainment has been linked in child height and stunting (Semba et al. 2008). Household location, defined as a rural versus urban area, is another known covariate potentially influence the relationship between independent factors with stunting outcome (Fotso 2007). Urban-rural differences are also partially linked to socioeconomic status and access to resources like water and sanitation infrastructure, health access, food supply, or education with households in rural areas faring worse (ibid).

A child's early life development may also affect the relationship between possible exposures and stunting outcome. Low birthweight among infants has been linked to similar stunting pathways including maternal undernutrition, restricted fetal intrauterine growth, and lower cognitive scores (Dewey and Mayers 2011, Dewey and Begum 2011, Walker et al. 2007). As a newborn enters infancy and early childhood, their growth trajectory depends on their age with differing growth rates between 0-23 months and 24-59 months (World Health Organization 2004b). Other studies have shown that first-born children have better health outcomes than children with later birth order (Biswas and Bose 2010, Jayachandran and Pande 2017). Increased household size and total number of children also negatively affects child development and household food security (Baig-Ansari et al. 2006, Naser et al. 2014). Prior studies had included household size cut-offs at five or six members to assess stunting association (Baig-Ansari et al. 2006). Finally, nutritional intake directly affects stunting and child growth and we included dietary diversity as a proxy for adequate nutrition (Dewey and Adu-Afarwuah 2008, Ruel and Arimond 2004).

CHAPTER 3: THEORETICAL FRAMEWORK

Child growth stunting is a complex phenomenon rooted in multi-factorial conditions (Subramanian, Mejía-Guevara and Krishna 2016). This dissertation investigated determinants of stunting by integrating two theoretical models: the Social Ecological Model and Life Course Perspective. In this chapter, the relative strengths and limitations of these models are assessed in stunting. Finally, a proposed integrated model guides the dissertation aims.

Social Ecological Model

The core research theme in this dissertation is that stunting moves beyond individual nutrition or single interventions and is instead embedded in larger structures. The Social Ecological Model was developed to highlight the interaction between individuals and their environmental settings including physical, social, and cultural dimensions, which are interdependent and nested within each other (Golden and Earp 2012, Stokols 1996). The original ecological models were developed by McLeroy et al. (1988) and Bronfenbrenner (1977) to examine people as embedded in larger structures and systems. McLeroy's ecological model categorized systems as: 1) individual, 2) interpersonal, 3) institutional, 4) community, and 5) policy factors (McLeroy et al. 1988). Later researchers and practitioners articulated how multiple levels reinforce each other and that public health interventions needed to target multiple levels (Golden and Earp 2012, Schölmerich and Kawachi 2016). We examined the five social ecological levels, detail their constructs, and apply them to child stunting.

The first level, the individual, was detailed as the diverse circumstances, attributes, and behaviors of a single person within their environment (McLeroy et al. 1988, Stokols 1996). Stunting has lifelong consequences including decreased cognitive, educational, and economic productivity (Galasso et al. 2017). Individual-level risk factors for child stunting includes maternal and child socioeconomic status, hygiene behavior, nutritional intake, intestinal health, maternal stress, and genetic predisposition (Subramanian, Mejía-Guevara and Krishna 2016). Aim 1 (Chapter 5) closely examined individual-level factors like maternal anthropometry and child gender. When interventions focused on single, individual factors to prevent stunting like nutrition, limited success in resolving stunted resulted (Humphrey et al. 2015, Smith et al. 2014). The Social Ecological Model posited that individuals are dependent on the circumstances of broader, external determinants (McLeroy et al. 1988).

The second social ecological level of interpersonal networks defined the close connections of the mother and child including partners, family members, peers, and social circles that disseminate health knowledge and propagate social norms (ibid). Interpersonal relationships, especially within the household, could have influenced child stunting development through economic attainment or nutritional behaviors (Naser et al. 2014). In this dissertation, social networks were not explicitly examined with stunting risk but indirectly included in household-level factors like wealth attainment, household size, and proximity to armed conflicts (Bhutta et al. 2019, Naser et al. 2014). Interpersonal connections of mothers and their children were similarly constrained by more macro factors (Stewart et al. 2013).

The third social ecological level included institutions, which were defined as formal and informal social institutions and organizations (McLeroy et al. 1988). Institutions influenced different physical, social, and cultural paradigms (Stokols 1996). In Madagascar or Zambia, institutions would include hospitals, religious organizations, schools, public spaces, and the local government. These institutions could affect access to healthcare, social cohesion, general wellbeing, and cultural norms (ibid). For example, if open defecation or failing to handwash are stigmatized at the institutional level, this could influence individuals and communities to act according to norms. However, institutions are also constrained by overarching governments. If armed conflicts overpowered a region, institutions supporting health education would be disrupted and unable to operate (Devakumar et al. 2014).

On the fourth level, the community was detailed as a collection of single institutions and organizations (McLeroy et al. 1988). The community level can influence many health outcomes and is an interdisciplinary approach (Stokols 1996). The community could include government agency coordination, non-governmental organizations, and cross-sector partnerships between hospitals, neighborhoods, religious organizations, and workplaces. Examples included the nationwide deployment of community health promoters or mass helminth de-worming at public schools (Leslie et al. 2011, Workie and Ramana 2013). Community-level interventions in stunting have involved disseminating hygiene and nutrition knowledge, building sanitation infrastructure, and providing post-trauma mental health care (Prendergast et al. 2015, Remans et al. 2011). In an opposite scenario, these same institutions could perpetuate stunting if organizations were not willing to collaborate or lack financial resources to intervene (Bhutta and Das 2014, Bhutta 2000).

The fifth and final social ecological level was defined as the policy level (McLeroy et al. 1988). When applied to stunting, policies include both legislative guidelines as well as macro structures like government functions and environmental considerations. Public policies help to improve public health from vaccinations to confer herd immunity to motor vehicle accident prevention (André 2006, World Health Organization 2004a). Policies could also be applied to stunting like expanding access to adequate sanitation at school and home, guaranteed food security, and deploying healthcare centers. The broader macro impacts of functioning governments also affects stunting. Governments steeped in political turmoil, dictatorships, or frequent armed conflicts lack the cohesion needed to coordinate complex resources (Devakumar et al. 2014).

These five social ecological levels overlapped with each other in multiple ways. First, incidents that occurred at one level affected multiple other levels (Stokols 1996). For example, if the Ministry of Health became dysfunctional, this would impact all hospitals and patients downstream. Second, different dimensions could interplay simultaneously like the occurrence of physical and social factors (ibid). For example, the combination of a drought-induced crop loss combined with dietary deficiencies could greatly exacerbate child stunting (Tranchant, Justino and Müller 2014). Third, cumulative effects can increase over time like conflicts or civil wars continuing to devastate individuals and communities long after their end (Devakumar et al. 2014, Stokols 1996). Finally, the interplay between individuals and their environments would differ depending on personal attributes; each person is affected differently by circumstances (Stokols 1996).

The overall strengths of the Social Ecological Model include the ability to examine health conditions beyond individuals or a single level and instead view health as embedded in external structures (McLeroy et al. 1988). Child stunting should be examined not only among individual children and their mothers but also as part of macro structures. The limitations of the Social Ecological Model in examining stunting included the inability to identify all levels, account for changes over time, and oversimplifying complex social structures. Additionally, social ecological levels have varying levels of impact on individuals and health conditions, which depends on context (Stokols 1996). For example, in child stunting, both national factors and international influences were relevant. The Social Ecological Model represented an appropriate framework to address stunting given the multifactorial and complex mechanisms at play.

Life Course Perspective

The Life Course Perspective examines individuals as ever-changing as they undergo transformative experiences and set life trajectories (Elder 1998). This framework uses a longitudinal view of a person set within history, social structures, and major life events. The life course was based on five principles: historical time and place, timing, linked lives, agency and lifespan development (Elder, Johnson and Crosnoe 2003). We applied these five principles to child stunting and research aims.

First, historical time and place rationalized that an individual's life is influenced by the occurrences during certain time period (Elder 1998). When considering stunting in historical time, volatile political events within a country may have resulted in instability that negatively affected child growth while globalization of the food supply chain could have increased child food security (Popkin 2006, Wagner et al. 2018). Second, timing was defined as the period in a person's life which would be disrupted or altered by an event as compared to a different time (Elder 1998). The concept of timing also considered the accumulation of risks over time (Elder, Johnson and Crosnoe 2003). Pregnancy and the first few years of life represent critical and vulnerable periods in determining child growth and overall health (Akresh, Caruso and Thirumurthy 2014, Duque 2017). Interventions to mitigate stunting had been recommended in the first 24 months of age, which could be turning points (Elder, Johnson and Crosnoe 2003, Prentice et al. 2013).

The third life course principle of linked lives described how individual experiences were interdependent and linked to the lives of others. Stunted children were closely linked to the lives of their mothers with her physical and mental wellbeing serving as strong determinants of linear growth and evidence of inter-generational effects of maternal and child stunting (Devakumar et al. 2014, Khatun et al. 2018). Child growth was also affected by the lives of their immediate families with socioeconomic status, household food insecurity, and household size as relevant stunting factors (Naser et al. 2014). Fourth, individual agency was the recognition that individuals have some autonomy in deciding their constraints and opportunities. Stunted children do not have control over their household wealth or nutrition but their caregivers could practice safe hygiene to prevent transmission of diseases, which could mitigate contamination and decrease EED risk (George et al. 2015a). The fifth principle of lifespan development viewed human development as a lifelong process through biological, psychological, and social changes. This last life course principle underscored how stunting, usually onset in early childhood, affected the individual throughout their life resulting in cognitive, economic, and developmental losses with intergenerational transfers to their children (Prentice et al. 2013, Walker et al. 2015).

The strengths of the Life Course Perspective in child stunting included a broad view of children nested within their historical time period, linked to their mothers' lives, and impacted throughout their lifespan. The life course concept of timing was especially valuable in understanding critical child developmental periods that could either worsen or improve stunting outcome while also contributing to accumulated disadvantages. The limitations of applying the Life Course Perspective to stunting included assumptions of temporality, homogeneity of events impacting individuals, magnitude of disadvantages, and lack of interactions between social or macro structures. For example, armed conflicts could be frequent but also varied in magnitude of personal impact while also affecting structures like the government, security, and supply chains. Overall, the Life Course Perspective grounded stunting examination in time and throughout life.

Integrated Conceptual Model

In this section, we proposed a conceptual model of child stunting that integrated the Social Ecological Model and Life Course Perspective, illustrated in Figure 3.1. We adapted aspects of the Social Ecological Model into the following levels: macro, community, household, and individual factors (McLeroy 1988). We also included elements of the Life Course Perspective depicting historical time, lifelong processes, timing, and the linked lives of children and their mothers (Elder 1998, Elder, Johnson and Crosnoe 2003).

The main goals of the integrated model were detailing how: 1) child height attainment was dependent on maternal health outcomes, 2) child stunting was influenced by external levels, 3) interlinked paradigms like social, political, and physical factors were involved in stunting, 4) timing of events during child developmental stages influenced stunting.

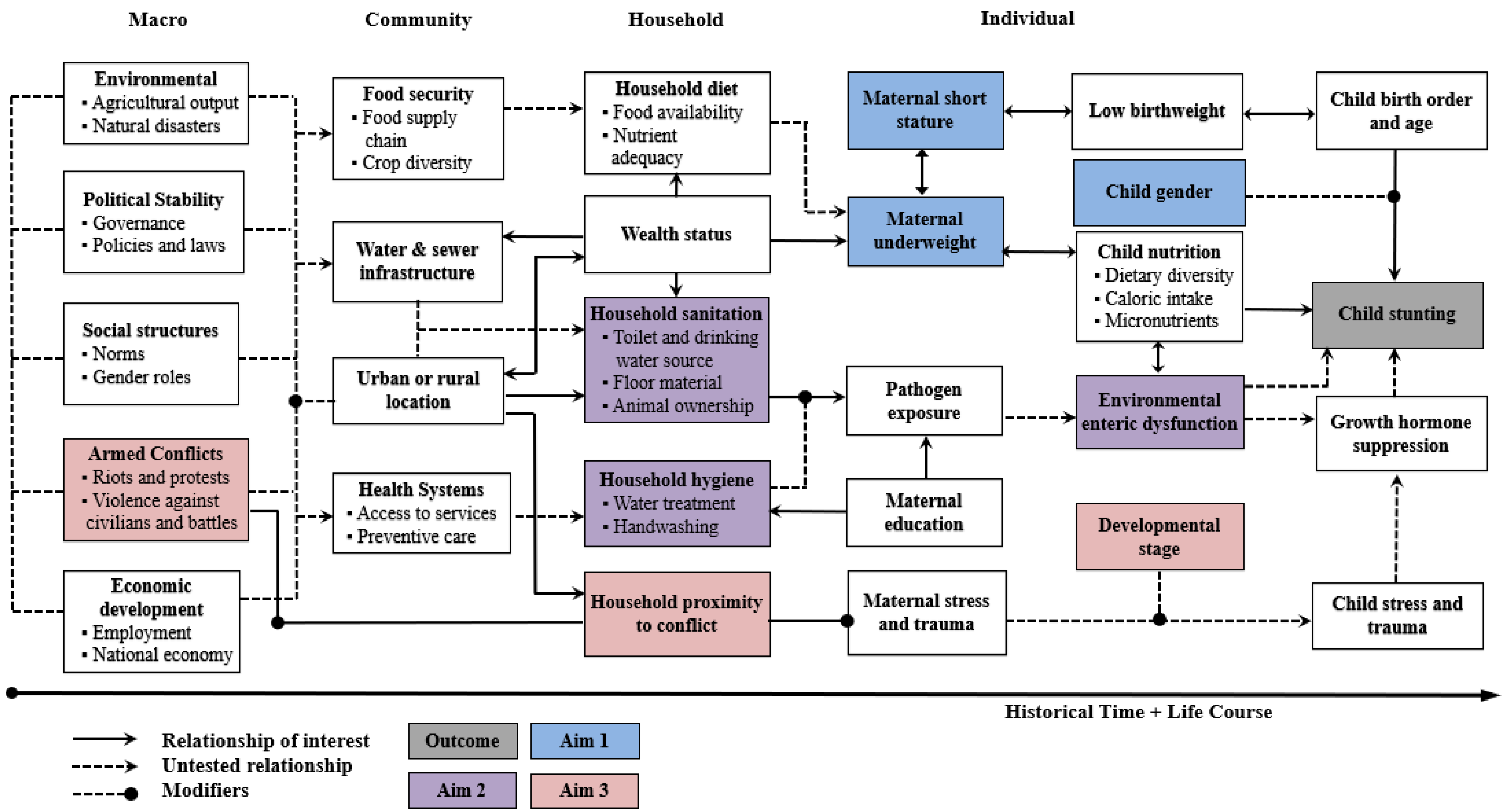
At the broadest level of the integrated model were the macro structures, which included environmental, political stability, social structures, armed conflicts, and economic development dimensions. Second, an intermediary community level included the role of health systems, food security, infrastructure, and geography. Third, the household level integrated household diet, wealth status, sanitation, hygiene, and proximity to armed conflicts. Finally, the individual level emphasized links between maternal health and child stunting. Mothers with short statures and underweight status would affect stunting through low birthweight infants and lack of adequate child nutrition. The model illustrated the possible effect of maternal education on hygiene practices and pathogen exposures. Finally, we posited that proximity to armed conflicts would lead to maternal stress and trauma, which would also increase child stress and trauma and potentially lead to stunting through growth hormone suppression.

The model captured major themes and was not inclusive of all possible pathways to stunting. Furthermore, several factors in the framework were not measurable. The arrow across the bottom represented the Life Course Perspective concept of historical time across the lifespan. The solid arrows in the diagram represented relationships of interest that would be potentially tested in the three aims. The arrows with dotted lines represented untested relationships and the circles with dotted lines were potential modifiers. While each level of the model appeared to be separate and distinct, the levels were not intended to be compartmentalized and mutually exclusive.

This conceptual framework guided the study aims in several ways. The main outcomes for all three aims were child stunting and height attainment. The integrated model depicted the multiple layers in stunting and progression across the life course. In the first aim (highlighted in blue), maternal characteristics included maternal nutritional status and height were explored with child gender, which incorporated both macro and individual dimensions. The second aim (highlighted in purple) examined water and sanitation infrastructure and household factors. The third aim (highlighted in red) investigated armed conflicts, which had implications at all levels and were moderated by critical developmental periods. There were also several factors that influenced the relationship between stunting and independent factors, including socioeconomic status, nutrition, household urban or rural location, and birth outcomes. These factors had been added as covariates in the statistical models detailed in later chapters.

The limitations of this integrated conceptual model included the inability to separate specific events, determine heterogeneity of events, or capture all factors or levels. For example, disruptive political events would have differing consequences for an individual child and this would vary depending on the socioeconomic status of the household. There were many unmeasurable factors and still more unknown factors in stunting. The strengths of the model included capturing the external structures at play in stunting and including time as an important component.

Figure 3.1. Integrated conceptual model of child stunting



CHAPTER 4: METHODS

Aim 1 Analytic Overview

Aim 1: To determine whether maternal anthropometry was associated with child stunting and height attainment.

1. Investigate whether maternal short stature was associated with child stunting and height attainment.
2. Examine if underweight or overweight in mothers was associated with child stunting and height attainment.
3. Compare rates of stunting and height attainment between male and female children.

Hypothesis 1a: Maternal short stature is associated with increased child stunting and lower height-for-age z-score (HAZ).

Hypothesis 1b: Underweight and overweight in mothers was associated with child stunting and lower HAZ.

Hypothesis 1c: Stunting and HAZ differences were observed between male and female children.

Study population:

The general study population consisted of 17,375 Malagasy and 17,064 Zambian women between the ages of 15-49 years and their children aged 0-59 months (0-5 years) with 12,448 in Madagascar and 13,517 in Zambia enumerated in the most recent Demographic and Health Surveys in Madagascar (MDHS 2008-2009) and Zambia (ZDHS 2013-2014). The restricted sub-sample for this aim included women and children with complete anthropometric data, needed to calculate stunting outcome, which are height-for-age z-scores. A total of 4,861 mother-child pairs (39% of total) in Madagascar and 11,407 mother-child pairs (84% of total) in Zambia met these criteria.

Outcome:

The primary outcome was child stunting, determined by the child's height, age, and sex compared to the WHO Growth Standards using height-for-age z-scores (HAZ). We used a binary stunting outcome with children defined as non-stunted (HAZ > -2) or stunted (HAZ ≤ -2). The secondary outcome was height-for-age z-score, which was used for the linear regression models to determine whether z-scores increase or decrease.

Predictors:

This aim focused on maternal anthropometry as the main predictor of child stunting. Maternal short stature is defined as women with height ≤ 145 cm (4 feet 9 inches) while maternal nutritional status is defined by body mass index (BMI) cutpoints, categorized as underweight (BMI < 18.5), normal (18.5 ≤ BMI < 25.0), or overweight (BMI ≥ 25). This aim also explores child gender, defined as male and female binary categories in the DHS.

Covariates:

Covariates that were either suspected confounders or mediators in our main models included child factors (birthweight, birth order, dietary diversity) and household variables (wealth).

Statistical Models:

We utilized multivariate logistic and linear regression models to analyze outcomes, predictors, and covariates. For Aim 1, we used gender-stratified models to observe any (detailed in the Analytic Plan section).

$Y \mid \eta_{\sim}$ Binary Logistic

$\ln(Y_{\text{child stunting}}) = X1_{\text{mom short}} + \text{covariates}$

Male: $\ln(Y_{\text{child stunting}}) = X1_{\text{mom short}} + \text{covariates}$

Female: $\ln(Y_{child\ stunting}) = X1_{mom\ short} + \text{covariates}$

$\ln(Y_{child\ stunting}) = X1_{momBMIstatus} + \text{covariates}$

Male: $\ln(Y_{child\ stunting}) = X1_{momstatus} + \text{covariates}$

Female: $\ln(Y_{child\ stunting}) = X1_{momstatus} + \text{covariates}$

$Y \mid \eta \sim$ Linear regression

$Y_{Child\ HAZ} = X1_{mom\ height} + \text{covariates}$

Male: $Y_{Child\ HAZ} = X1_{mom\ height} + \text{covariates}$

Female: $Y_{Child\ HAZ} = X1_{mom\ height} + \text{covariates}$

$Y_{Child\ HAZ} = X1_{mom\ BMI} + \text{covariates}$

Male: $Y_{Child\ HAZ} = X1_{mom\ BMI} + \text{covariates}$

Female: $Y_{Child\ HAZ} = X1_{mom\ BMI} + \text{covariates}$

Where:

$\ln(Y_{child\ stunting})$ = logistic/logit regression on child stunting outcome (non-stunted vs. stunted)

$Y_{Child\ HAZ}$ = linear regression on continuous child height-for-age z-score outcome

$X_{mom\ short}$ = independent variable of mom's short stature (short vs. normal)

$X_{momBMIstatus}$ = independent variable of mom's BMI indicator (underweight, normal, overweight)

$X_{mom\ height}$ = independent continuous variable of mom's height (cm)

$X_{mom\ BMI}$ = independent continuous variable of mom's BMI score

Covariates = (child sex, wealth quintile, birthweight, dietary diversity, birth order)

Aim 2 Analytic Plan

Aim 2: To examine whether indicators of household sanitation and hygiene were associated with child stunting and height attainment.

1. Identify whether the highest quality toilets were associated with child stunting and height attainment.
2. Investigate whether the highest quality drinking water source was related to child stunting and height attainment.
3. Examine whether the highest quality of household floor materials was associated with child stunting and height attainment.
4. Explore whether other exposures like presence of animals and hygiene behaviors were associated with stunting.

Hypothesis 2a: Households with less-than-best quality toilet were associated with higher odds of stunting and lower HAZ.

Hypothesis 2b: Households with less-than-best quality drinking water infrastructure were associated with higher odds of stunting and lower HAZ.

Hypothesis 2c: Households with low quality floor materials were associated with higher stunting and lower HAZ.

Hypothesis 2d: Ownership of contamination-linked animals and not practicing proper hygiene was associated with higher odds of stunting and lower HAZ.

Study population:

The general study population consisted of 17,375 Malagasy and 17,064 Zambian women between the ages of 15-49 years and their children aged 0-59 months (0-5 years) with 12,448 in Madagascar and 13,517 in Zambia enumerated in the most recent Demographic and Health Surveys in Madagascar (MDHS 2008-2009) and Zambia (ZDHS 2013-2014). The restricted sub-sample for this aim included women and children with complete anthropometric data, needed to calculate stunting outcome, which are height-for-age z-scores. A total of 4,861 mother-child pairs (39% of total) in Madagascar and 11,407 mother-child pairs (84% of total) in Zambia met these criteria.

Outcome:

The primary outcome was child stunting, determined by the child's height, age, and sex compared to the WHO Growth Standards using height-for-age z-scores (HAZ). We used a binary stunting outcome with children defined as non-stunted (HAZ > -2) or stunted (HAZ ≤ -2). The secondary outcome was height-for-age z-score, which was used for the linear regression models to determine whether z-scores increase or decrease.

Predictors:

Aim 2 focused on household sanitation and hygiene as a predictor for stunting through contamination and intestinal health pathways. Sanitation was operationalized as having an advanced flush toilet, piped drinking water source in the household, and advanced floor materials. Other related variables explored in the models included whether the household shared a toilet, owned certain animals, and treated drinking water.

Covariates:

Covariates that were either suspected confounders or mediators in our main models included child factors (age category), maternal characteristics (education), and household variables (wealth quintile, urban/rural location).

Statistical Models:

We utilized multivariate logistic and linear regression models to analyze stunting outcome, predictors, and covariates.

Sanitation Models

$Y \mid \eta \sim$ Binary Logistic

$\ln(Y_{stunting}) = X1_{flush} + X2_{animals} + X3_{shared} + \text{covariates}$

$\ln(Y_{stunting}) = X1_{piped} + X2_{animals} + X3_{treat} + \text{covariates}$

$\ln(Y_{stunting}) = X1_{floor} + X2_{animals} + X3_{diarrhea} + \text{covariates}$

$Y \mid \eta_{\sim}$ Linear regression

$Y_{HAZ} = X1_{flush} + X2_{animals} + X3_{shared} + \text{covariates}$

$Y_{HAZ} = X1_{piped} + X2_{animals} + X3_{treat} + \text{covariates}$

$Y_{HAZ} = X1_{floor} + X2_{animals} + X3_{diarrhea} + \text{covariates}$

Where:

$\ln(Y_{child\ stunting})$ = logistic regression on child stunting outcome (non-stunted vs. stunted)

$Y_{child\ HAZ}$ = linear regression on continuous child height-for-age z-score outcome

X_{flush} = advanced flush toilet in household (yes vs. no)

X_{piped} = piped drinking water source in household (yes vs. no)

X_{floor} = finished floor materials (yes vs. no)

$X_{animals}$ = own any chickens, pigs, or cattle (yes vs. no)

X_{shared} = toilet is shared with other households (yes vs. no)

X_{treat} = any treatment of drinking water (yes vs. no)

$X_{diarrhea}$ = recent diarrhea in the last two weeks (yes vs. no)

Covariates = child age category, household wealth, mother's education, urban or rural location

Aim 3 Analytic Overview

Aim 3: To investigate whether armed conflict exposures among children and their mothers were associated with child stunting and height attainment.

1. Examine whether any conflict exposure and number of conflicts during critical developmental periods (pregnancy and first year of life) were related to increased stunting.
2. Explore whether associations between stunting and conflict differed by type of conflict and distance from household.

Hypothesis 3a: Armed conflict exposure during pregnancy were associated with increased child stunting odds and lower height-for-age z-score (HAZ).

Hypothesis 3b: Armed conflict exposure during a child's first year of life were associated with increased child stunting odds and lower HAZ.

Hypothesis 3c: Varying distances of conflicts from the households and types of violent conflict had different odds of stunting association and HAZ.

Study population:

The Armed Conflict Location and Event Database (ACLED) included publicly reported armed conflicts in Madagascar and Zambia between 1997 to the present with 875 armed conflict events in Madagascar and 1,135 armed conflict events in Zambia. Conflict event details and GPS coordinates were matched with DHS data based on geographic proximity and event dates and resulted in a total of 318 eligible conflicts (36.3%) in Madagascar and 889 conflicts in Zambia (78.3%).

The general study population consisted of 17,375 Malagasy and 17,064 Zambian women between the ages of 15-49 years and their children aged 0-59 months (0-5 years) with 12,448 in Madagascar and 13,517 in Zambia enumerated in the most recent Demographic and Health Surveys in Madagascar (MDHS 2008-2009) and Zambia (ZDHS 2013-2014). The restricted sub-sample for this aim included women and children with complete anthropometric data, needed to calculate stunting outcome, which are height-for-age z-scores. A total of 4,861 mother-child pairs (39% of total) in Madagascar and 11,407 mother-child pairs (84% of total) in Zambia met these criteria.

Outcome:

The primary outcome was child stunting, determined by the child's height, age, and sex compared to the WHO Growth Standards using height-for-age z-scores (HAZ). We used a binary stunting outcome with children defined as non-stunted (HAZ > -2) or stunted (HAZ ≤ -2). The secondary outcome was height-for-age z-score, which was used for the linear regression models to determine whether z-scores increase or decrease.

Predictors:

Aim 3 focused on maternal and child exposure to conflicts as predictors of stunting. Exposure to conflicts was determined by using GPS coordinates between DHS household clusters with ACLED conflict events located within a specific distance. We explored whether conflicts occur within a circular radius of 50km, 100km, or 250km of a household. We used birth dates and conflict dates to base our calculations of violence exposure at different buffer distances and developmental time periods: exposure during pregnancy (10-month period before birth of child) and first year of life (first 14 months). The specific type of conflict including fatal conflicts, battles, riots/protests, and violence against civilians was examined with stunting.

Covariates:

Covariates that were either suspected confounders or mediators in our main models included child factors (birthweight, dietary diversity) and household variables (wealth quintile, urban/rural location).

Statistical Models:

For Aim 3, we utilized bivariate and multivariate logistic and linear regression models to analyze stunting outcome, predictors, and covariates.

Y | η ~ Binary Logistic

50km, 100km, 250km during pregnancy:

$\ln(Y_{child\ stunting}) = X1_{any\ conflict} + covariates$

$\ln(Y_{child\ stunting}) = X1_{fatal\ conflicts} + covariates$

$\ln(Y_{child\ stunting}) = X1_{battle} + covariates$

$\ln(Y_{child\ stunting}) = X1_{riots/protests} + covariates$

$\ln(Y_{child\ stunting}) = X1_{violence\ against\ civilians} + covariates$

50km, 100km, 250km during first year of life:

$\ln(Y_{child\ stunting}) = X1_{any\ conflict} + covariates$

$\ln(Y_{child\ stunting}) = X1_{fatal\ conflicts} + covariates$

$\ln(Y_{child\ stunting}) = X1_{battle} + covariates$

$\ln(Y_{child\ stunting}) = X1_{riots/protests} + covariates$

$\ln(Y_{child\ stunting}) = X1_{violence\ against\ civilians} + covariates$

Y | η ~ Linear regression

50km, 100km, 250km during pregnancy:

$Y_{Child\ HAZ} = X1_{\#\ conflicts} + covariates$

$Y_{Child\ HAZ} = X1_{\#\ fatal\ conflicts} + covariates$

$Y_{Child\ HAZ} = X1_{\#\ battles} + covariates$

$Y_{Child\ HAZ} = X1_{\#\ riots/protests} + covariates$

$Y_{Child\ HAZ} = X1_{\#\ violence\ against\ civilians} + covariates$

50km, 100km, 250km during first year of life:

$Y_{Child\ HAZ} = X1_{\#\ conflicts}$ + covariates

$Y_{Child\ HAZ} = X1_{\#\ fatal\ conflicts}$ + covariates

$Y_{Child\ HAZ} = X1_{\#\ battles}$ + covariates

$Y_{Child\ HAZ} = X1_{\#\ riots/protests}$ + covariates

$Y_{Child\ HAZ} = X1_{\#\ violence\ against\ civilians}$ + covariates

Where:

$\ln(Y_{child\ stunting})$ = logistic/logit regression on child stunting outcome (non-stunted vs. stunted)

$Y_{Child\ HAZ}$ = linear regression on continuous child height-for-age z-score outcome

$X_{any\ conflict}$ = whether any conflict occurred during time period (yes vs. no)

$X_{fatal\ conflicts}$ = whether a fatal conflict occurred (yes vs. no)

X_{battle} = whether a battle occurred (yes vs. no)

$X_{riots/protests}$ = whether a riot/protest occurred (yes vs. no)

$X_{violence\ against\ civilians}$ = whether violence against civilians occurred during time period (yes vs. no)

$X_{\#\ conflicts}$ = number of conflicts that occurred during time period

$X_{\#\ fatal\ conflicts}$ = number of fatal conflicts that occurred

$X_{\#\ battles}$ = number of battles that occurred

$X_{\#\ riots/protests}$ = number of riots/protests that occurred

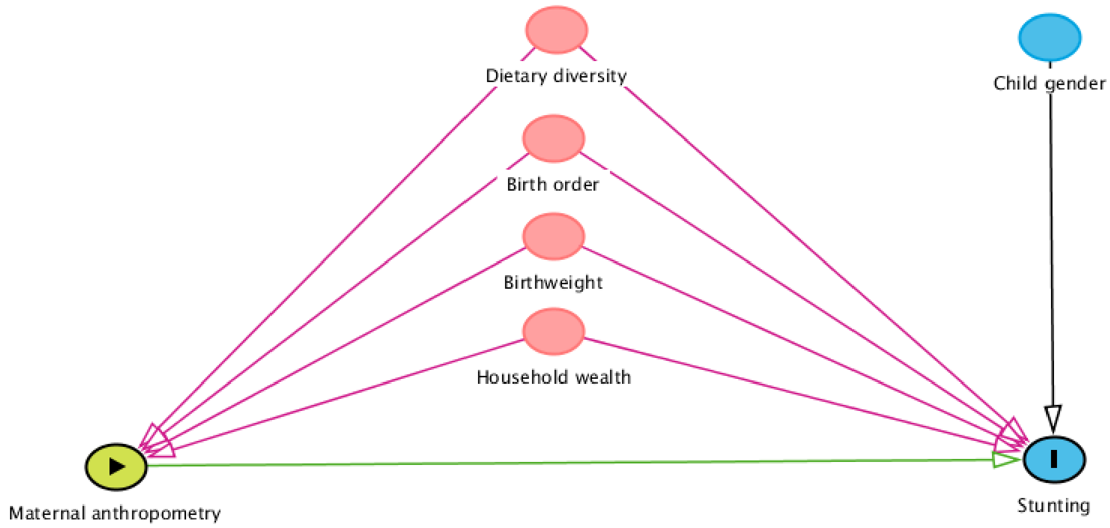
$X_{\#\ violence\ against\ civilians}$ = number of violence against civilian events that occurred

Covariates = (household wealth, low birthweight, urban or rural location, dietary diversity)

Directed Acyclic Graphs (DAGs)

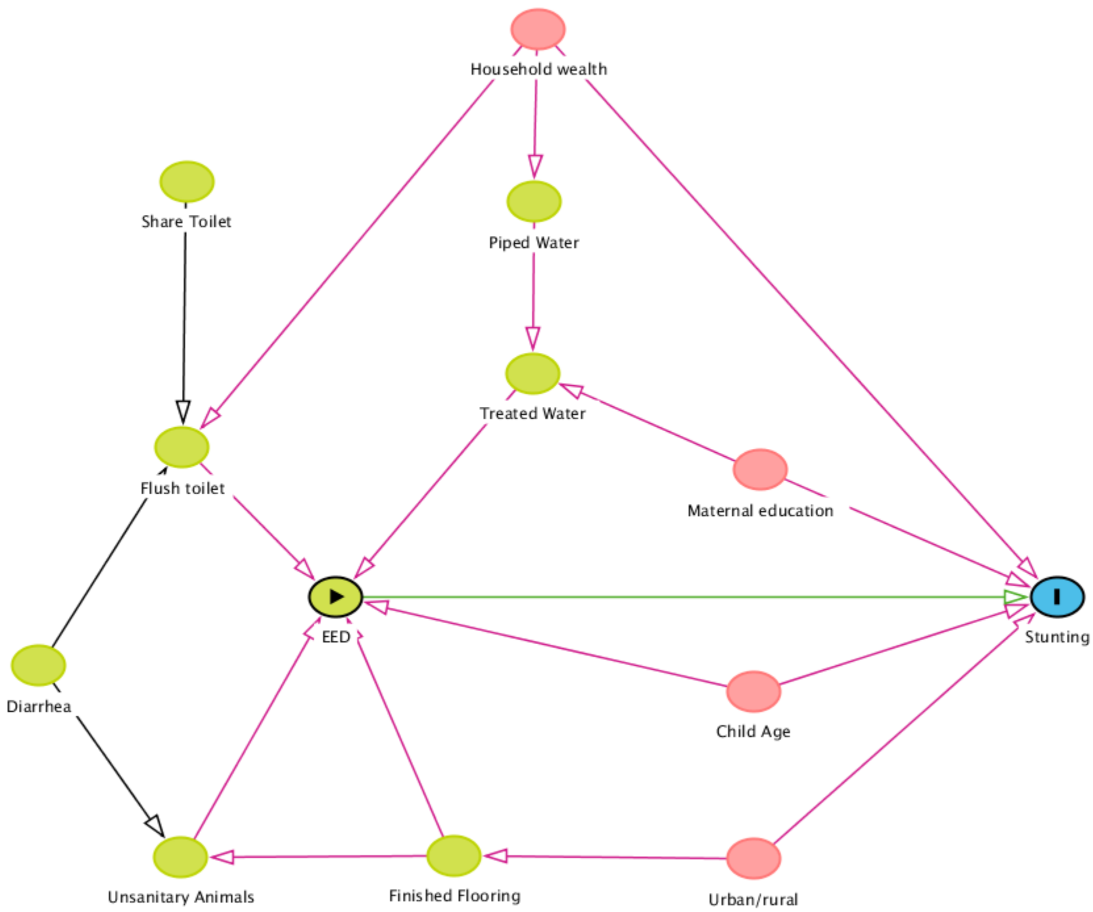
Directed Acyclic Graphs (DAGs) are epidemiologic causal diagrams that serve as a logical mechanisms on how variables operate in a causal fashion along the exposure to outcome pathway (Rothman, Greenland and Lash 2008). DAGs have arrows that function unidirectionally to infer causality. The analyses in this dissertation were guided by DAGs to represent stunting outcome, predictors, and covariates for each study aim. The DAG illustrations were created in DAGitty web and desktop software (Textor et al. 2016). The main predictor (yellow-green circle with triangle) was on the pathway to the outcome (blue circle with "I"). Blue circles were testable variables while white circles were unmeasured variables on the pathway from the predictor to outcome. Red circles were not on the causal pathway but likely confounded the relationship between main exposures and outcomes. Red paths represented the confounding pathways that needed to be adjusted for in statistical models. Green arrows represented direct pathways that did not need adjustment. While DAGs created a logical diagram to test variables between an outcome and predictor, DAGs were unable to test the magnitude or strength of associations.

Figure 4.1 Aim 1 DAG of maternal anthropometry and child gender factors with child stunting outcome



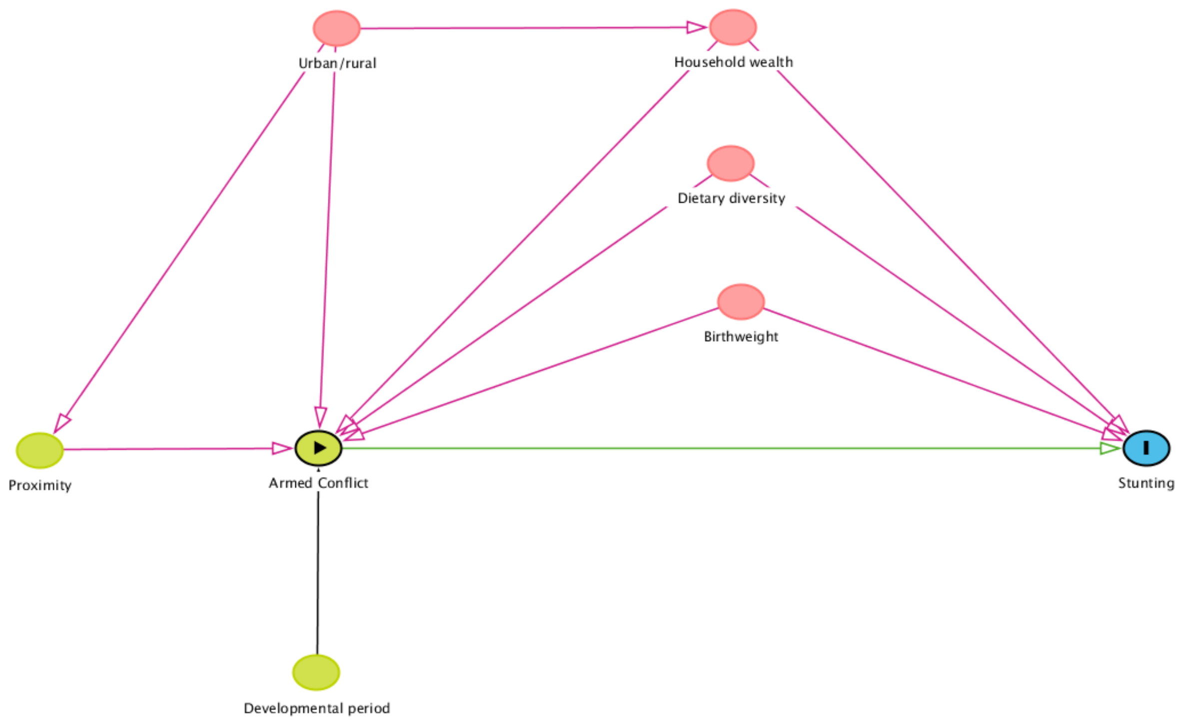
Aim 1 was represented as a DAG in Figure 4.1 between maternal characteristics, including maternal anthropometry, which were defined as maternal height attainment and nutritional status, with child stunting outcome. Maternal height was operationalized as maternal short stature while nutritional status was classified as normal, underweight, or overweight. We hypothesized that short stature and underweight mothers were associated with stunting in their children. Child gender was shown as a possible moderator of stunting but the true causal relationship was unknown. Known covariates between the outcome and predictor included child dietary diversity, birth order, birthweight, and household wealth.

Figure 4.2 Aim 2 DAG of sanitation predictors on child stunting outcome



Aim 2 was represented as a DAG in Figure 4.2 between household sanitation on stunting outcome. The main predictors were operationalized as having an advanced flush toilet, piped water access, and finished flooring. Hygiene behaviors like handwashing, treating drinking water, presence of unsanitary animals (pigs, chickens, and cattle), and recent diarrhea operated on the pathway between household sanitation to stunting. We hypothesized that households lacking the most advanced sanitation infrastructure would be associated to child stunting. These predictors were on the causal path to stunting due to unobserved fecal-oral contamination and intestinal absorption dysfunction. Covariates included child age, maternal education, household wealth, and urban/rural location.

Figure 4.3 Aim 3 DAG of armed conflict exposure with child stunting outcome



Aim 3 was represented as a DAG in Figure 4.3 between armed conflicts predictors with child stunting outcome. The main predictor of violent conflict exposure was measured at 50km, 100km, and 250km radial distances from households. Conflict exposures were assessed at two time points: during pregnancy and the child's first year of life. These critical exposure periods were hypothesized to determine the impact on child height attainment and were linked to stunting through child birthweight and through unobservable pathways including child trauma, maternal trauma, and growth hormone suppression. We also assessed whether the type of armed conflict would be associated with stunting. Covariates included child dietary diversity, birthweight, household wealth, and urban/rural location.

Databases

The databases used for this dissertation included the Madagascar Demographic and Health Survey (DHS) IV, Zambia DHS V, Madagascar Armed Conflict Location and Event Data Project (ACLED), and Zambia ACLED. The DHS data are the largest nationally representative health and demographic datasets available for both countries with reliable measures of height-for-age z-scores for individuals. The DHS and ACLED datasets were merged for each country using GPS coordinates at 50km, 100km, and 250km distances. All statistical analyses were performed in SAS 9.4 and geospatial analyses in ArcGIS Desktop 10.5.

Demographic and Health Surveys (DHS)

The Demographic and Health Surveys (DHS) is a data collection program funded by USAID (U.S. Agency for International Development) and implemented by ICF International. The DHS began in 1984 and has been conducted in over 90 low- and middle-income countries through the collection of nationally representative data on health topics including maternal and child health, nutrition, environmental health, malaria, HIV/AIDS, reproductive health approximately every five years with targeted surveys on specific health issues collected periodically. The cross-sectional data used face-to-face interviews with large sample sizes of women and men across regions in each program country. Data were collected by local field teams, electronically entered, manually and automatically cleaned, and made publicly available.

The Madagascar and Zambia DHS were nationally and regionally representative for each country, which was accomplished using a two-stage, probability cluster sampling design beginning in the first stage which drew enumeration areas from national census files (DHS Program 2017b). Next, household samples were selected from each enumeration area in the second stage. DHS standard surveys were typically conducted over 18-20 months. In each standard survey, a household, women's, and men's questionnaires were completed. Data on children aged 0-59 months in each household were also collected. Some DHS standard surveys also collected additional data including biomarkers and geographic information. DHS conducted periodic non-standard surveys including an AIDS Indicator Survey, Service Provision Assessment, Malaria Indicator Survey, Key Indicators Survey, and qualitative research (DHS Program 2017b).

DHS anthropometry included with complete height and weight data collected by trained interviewers. In Madagascar, maternal anthropometry was only collected for mothers with children. The DHS surveys also included age, child gender, and height-for-age z-scores calculated for each child with anthropometric data. All data were anonymous without disclosure of names of individuals and aggregated in analyses.

The DHS program required a brief application to obtain permission for investigators to analyze data for research or programmatic purposes but no additional ethics or IRB (Institutional Review Board) approval were specifically required. Approval was sought and granted for use of Madagascar and Zambia DHS data by DHS administrators for this dissertation.

DHS Anthropometric Data

The DHS included height-for-age z-scores calculated for each child using the 2006 WHO Child Growth Standards (Central Statistical Office, Ministry of Health Zambia and ICF International 2014). The WHO Growth Standards included a reference study, which sampled children in six countries (Brazil, Ghana, India, Norway, Oman, and United States) across ethnic, social, economic, or nutritional differences.

The DHS took height and weight anthropometric measurements from Malagasy and Zambian household among eligible women age 15-49 years, men 15-49 years, and children under five years in addition to other biomarkers. Two trained data collectors jointly used a mechanical needle scale for weight and a Shorr height board for height according to a detailed protocol (Central Statistical Office, Ministry of Health Zambia and ICF International 2014, ICF International and Demographic and Health Surveys 2012:11-22, National Institute of Statistics Madagascar and ICF Macro 2010). Based upon measured values, BMI (body mass index) and height-for-age, weight-for-age, and height-for-weight z-scores were calculated to determine individual standard deviation range. The weight and height values were appended to household and individual questionnaires. Height and weight anthropometric measurements were taken from each household among eligible women aged 15-49 years and children under six years, although DHS limited data to children five years or under.

DHS GIS Data

Geographic data was collected using GIS (Geographic Information Systems) software and GPS (Global Positioning System) navigation coordinates to measure elevation and latitude and longitude coordinates (DHS Program 2017a). The DHS used recreational grade GPS receivers, which provided an accuracy range of 10-15 meters and required a field team, the use of a GPS eTrex receiver, power supply, GPS/PC connector cables, GPS TrackMaker utility software, and paper record (Burgert, Zachary and Colston 2013:1-9). The cluster number, GPS-receiver number, waypoint name, latitude in decimals, longitude in decimals, and elevation in meters are recorded on paper and appended to DHS household questionnaires. DHS had created measures to protect participant and household confidentiality by modifying random GPS coordinates to prevent unmasking. Each cluster GPS coordinate was displaced 2 km in urban areas and 5km in rural areas with 1% of rural clusters displaced up to 10km (DHS Program 2012). DHS cautioned that random error can result from displacement and measuring short, direct distances from a household to a precise location would be inaccurate.

Madagascar DHS

In Madagascar, the most recent standard DHS survey dataset was the Madagascar DHS Version IV (MDHS) with data collected from November 2008 to August 2009 by the National Institute of Statistics of Madagascar (INSTAT) under the Department of Demography and Social Statistics with technical assistance from ICF Macro International. Informed consent documents were prepared by ICF Macro and submitted to the Madagascar Ethics Committee of the Vice Prime Minister Responsible for Public Health for approval. There has been no updated standard DHS Madagascar collection since 2009 but a targeted interim survey for malaria indicators (MIS) was conducted in 2011, 2013, and 2016. We used the most recently available dataset for Madagascar in our analyses. The corresponding global DHS recode manual for MDHS IV was DHS V, the fifth version of variables and coding.

The 2008-2009 Madagascar DHS IV conducted surveys with 17,857 households consisting of 17,375 women aged 15-49 years, 8,586 men aged 15-59 years, and 12,448 children 0-59 months old. The two-stage sampling design collected representative data at the national and regional level. This fourth version of the Madagascar DHS is the most recent version and serves as an update from the previous versions collected in 1992, 1997, and 2002-2003. The MDHS selected 600 clusters for survey enumeration and surveyed 596 clusters. In each cluster, 32 households were selected totaling 17,857 households surveyed and 17,857 eligible women aged

15-49 years were interviewed with a 96% response rate. The MDHS also included anthropometric measures from a sub-set of their study sample as a supplemental component women and children under five.

Zambia DHS

In Zambia, the most recent DHS survey dataset was the Zambia Standard DHS Version V (ZDHS), the fifth standard DHS survey, with data collected from August 2013 to April 2014 by the Zambia Central Statistical Office and financed primarily through the Ministry of Health and Ministry of Finance (Central Statistical Office, Ministry of Health Zambia and ICF International 2014). The corresponding global DHS recode manual for the ZDHS V is the DHS VI, the sixth version of variables and coding. The ZDHS used a two-stage sampling frame with census enumeration areas from 722 clusters in the first stage and a representative sample selection of 18,052 households in the second stage. A total of 15,920 households were successfully interviewed with a 98% household response rate (Central Statistical Office, Ministry of Health Zambia and ICF International 2014). The surveys included 17,064 eligible women aged 15-49 years and 16,209 eligible men aged 15-59 years with 91% participant response rates. The ZDHS also included anthropometric measures as a supplemental component women and children under five.

Global Administrative Areas Database (GADM)

The GADM Database Version 2.8 contains geographic information data on over 200 countries (Hijmans 2015). This open access database has administrative boundary shapefiles at different levels in various compatible shapefile formats. The GADM coordinate reference system uses longitude and latitude data under the World Geodetic System (WGS) 84 (Hijmans 2015). For this dissertation, we used geopolitical administrative boundary areas defined by the governments in Madagascar and Zambia. For example, this included regions and zones defined by each country. These data were used as vector shape files imported into ArcGIS. The administrative boundaries drew clear lines between governance areas in each country and were matched to DHS region variables.

Armed Conflict Location and Event Data Project (ACLED)

The Armed Conflict Location and Event Data Project (ACLED) is a dataset of disaggregated armed conflict events, which includes the dates and locations of reported political violence and protest events in 55 African and Asian countries through secondary sources including news media, books, periodicals, and humanitarian reports (Raleigh 2016). The purpose of ACLED was to provide data for conflict analysis and crisis mapping. All data were made publicly available, without needing administrator approval, in Microsoft Excel and GIS formats. Documentation for user guides, codebooks, and visuals were also publicly available. Each data observation contained: a date and location of the conflict event, GPS coordinates, descriptions of the specific event type (civilian killings, riot, protests, and recruitment activities), type of actors (rebels, governments, militias, armed groups, protestors, and civilians), changes in territorial control, and number of reported fatalities (Raleigh and Dowd 2017).

ACLED received conflict event data from multiple sources on a weekly basis including new reports, civil society publications, human rights publications, and security updates. For this dissertation, the ACLED database version 7 from January 1997 to December 2016 were downloaded for Madagascar and Zambia. The events were restricted to match the DHS data collection dates and exposure time periods of interest (Raleigh 2016). The database did not contain any confidential or personally identifiable information. ACLED was considered reliable and verifiable by peer reviewers in multiple disciplines including academia, country experts, and policy communities (ACLED 2017:11). ACLED researchers caution that fatality data could be biased and conflicting since deaths were not verified by researchers; the database used the most conservative estimates. The ACLED database was selected for use in this dissertation instead of the Uppsala Conflict Data Program (UCDP), which is the other publicly available GIS-based conflict dataset, because ACLED had great conflict reports and more comprehensive data for each event (Uppsala University 2016). UCDP had 43 events from 2002-2012 in Madagascar and 12 events from 1989-2001 in Zambia, far fewer than ACLED.

The Madagascar ACLED Database Version 7 contained a total of 875 conflict events with the first record from July 20, 1997 and last record on December 29, 2016 (Raleigh 2016). For the purposes of this dissertation, only conflict events occurring 2009 or earlier were included to match DHS survey timepoints and establish temporality. This restricted the ACLED data to a total of 318 conflict events, or 36.3% of the full database. The Zambia ACLED Database Version 7 contained a total 1,135 conflict events with the first record from March 9, 1997 and last record on December 15, 2016. For temporality reasons in matching the data with DHS, only conflict events occurring before 2014 were included. The restriction resulted in a total of 889 ACLED conflict events, or 78.3% of the full database.

Conflict Sensitivity Analyses

The existing academic literature on specific proximity to an armed conflict event and potential maternal and child health outcomes was lacking. This dissertation contributed one of few examinations of disaggregated conflict data with child stunting outcomes at the individual and household levels. Limited published studies guided the research on appropriate geographic distances from an armed conflict that would potentially affect individuals and households. We replicated distances suggested by past studies and also created new buffer distances (Bhutta et al. 2019, Wagner et al. 2018). In this dissertation, we used three different buffer distances to serve as a sensitivity test of distance between households and a conflict event at: 50km, 100km, 250km. Buffers represented a radial distance, which encompass a circular area. The center of each of the buffer areas contained the DHS household cluster. We then explored how many and what type of conflicts fall within the buffer in Chapter 7.

CHAPTER 5: AIM 1 – MATERNAL ANTHROPOMETRY AND CHILD GENDER

Abstract

Introduction: Stunting, a linear growth deficit, affected nearly one-quarter of children globally. Stunting has potential intergenerational effects where stunted mothers tend to have stunted children. Differences between stunting risk among male and female children had also been documented but these relationships remain unclear.

Methods: We analyzed cross-sectional data of 4,861 mother-child pairs from the 2008-2009 Madagascar and 11,407 mother-child pairs from the 2013-2014 Zambia Demographic and Health Surveys. Our main outcomes were child stunting and height-for-age z-scores. We assessed whether child stunting and HAZ was associated with maternal short stature (height < 145cm), and BMI (body mass index) status. We controlled for potential confounders including household wealth, birthweight, dietary diversity, and birth order.

Results: Children with short statured mothers had double the odds of stunting (MDHS: aOR = 2.07, 95% CI: 1.39, 3.08; ZDHS: aOR = 2.66, 95% CI: 1.69, 4.20) compared to children with normal statured mothers. Underweight in mothers was associated with higher child stunting odds (MDHS: aOR = 1.43, 95% CI: 1.12, 1.84; ZDHS: aOR = 1.41, 95% CI: 1.13, 1.75) in both Madagascar and Zambia but overweight in mothers was associated with decreased stunting in Zambia only (ZDHS: aOR = 0.82, 95% CI: 0.69, 0.97). We examined whether differences in stunting were observed between male and female children and found that coefficient estimates differed but had overlapping confidence intervals and may not signify a true difference.

Discussion: We found associations between maternal short stature and BMI status with child stunting. Differences in stunting odds were also observed between male and female children but

the implications are unclear. Future research and programs should consider the role of maternal health and child gender.

Introduction

Stunting affected nearly one-quarter of children under five globally with the highest burden in low- and middle-income countries in 2017 (UNICEF, WHO and World Bank Group 2018). Despite widespread occurrence, the etiology of stunting remains unclear. Nutritional interventions have failed to resolve stunting long-term. When stunting persists beyond childhood, individuals suffer lifelong consequences including cognitive impairment, lower educational attainment, and lower lifetime earnings (Onis, Blossner and Borghi 2011, Walker et al. 2015). Stunting is also posited as an intergenerational phenomenon where stunted mothers tend to have stunted children (Child Health Epidemiology Reference Group Small-for-Gestational-Age/Preterm Birth Working 2015, Martorell and Zongroneb 2012). Additionally, undernourished mothers also tend to have undernourished children (Jeric et al. 2013). Finally, stunting rates differ between male and female children in different countries, which suggested the potential role of gender differences and cultural practices (Wamani et al. 2007).

In this analysis, we explored the association between maternal anthropometry measures with child stunting. First, we examined maternal linear growth using height measurements. Women were defined as having very short stature if their height fell below 145 cm (4 feet and 9 inches). This cutoff point was developed after extensive studies associated increased obstetric risks with women 140-150 cm tall (Child Health Epidemiology Reference Group Small-for-Gestational-Age/Preterm Birth Working 2015, United Nations ACC/SCN 1992). Short stature mothers had more adverse neonatal and child health outcomes including low birthweight, preterm birth, child mortality, stunting, and other conditions compared to normal or tall statured mothers (Arendt, Singh and Campbell 2018, Khatun et al. 2018). Impaired linear growth in children was predicted to occur as early as *in utero* with neonates born small-for-gestational age, which was also associated with short stature mothers (Shrimpton et al. 2001). As a second and alternate measure, we also used maternal height-for-age standard deviations provided by the Demographic and Health Surveys (Central Statistical Office, Ministry of Health Zambia and ICF International 2014). However, since the reference population is female children aged 17 years from the United States, we did not consider height-for-age reliable and only used this definition for sensitivity analyses. Since there was no universally agreed upon indicator for adult stunting like scales used for children, we used short stature height cut-offs from prior studies for mothers in our sample but note that this was a limitation.

Genetics could explain some of the association between short maternal height and stunting in children but would not fully account for height attainment. One multi-ethnic study found that in countries where both parental and child environmental conditions were optimal, the child's height potential matched the average height of both parents (Garza et al. 2013). The same study found that in cases where young children fared better than their parents through targeted interventions during infancy, their projected height exceeded their parents' averaged heights, which supports the need for early childhood intervention (ibid). Moreover, studies that compared migrant children in the United States and New Zealand to children in their country of origin found that migration led to catch-up growth with increased heights and reduced stunting risk but also increased obesity in young children (Schumacher, Pawson and Kretchmer 1987, Smith et al. 2003, Stillman, Gibson and McKenzie 2012).

Maternal stature was one determinant of stunting risk in prior studies while maternal nutritional status was another previously researched predictor of child height and stunting (Child Health Epidemiology Reference Group Small-for-Gestational-Age/Preterm Birth Working 2015, Jeric et al. 2013, Khatun et al. 2018, Rahman et al. 2015). We examined maternal nutritional status using BMI (body mass index) assessments to assess maternal overweight and underweight (Jeric et al. 2013, Rahman et al. 2015). BMI is a function of body weight divided by height squared and is divided into: underweight (BMI < 18.5), normal ($18.5 \leq$ BMI < 25.0), and overweight (BMI ≥ 25.0) (Keys et al. 1972). In low- and middle-income countries, underweight and overweight maternal statuses were associated with adverse birth outcomes (Rahman et al. 2015). Underweight in mothers was linked to small for gestational age births, lower birthweight, pre-term birth, and shorter infant length (Jeric et al. 2013). One study found that higher maternal BMI led to increased height-for-age z-scores in children, which was a generally positive outcome (Bhalotra and Rawlings 2011). However, overweight or obesity in mothers were associated with higher risk of pre-term birth, pre-eclampsia, gestational diabetes, and having a large for gestational age infant (Choudhury et al. 2016, Lynch et al. 2014, Zhao et al. 2018). An epidemiologic paradox of having both undernourishment and overweight populations in a developing country complicates the effect of maternal BMI on child stunting (Dieffenbach and Stein 2012). The evidence between maternal BMI status and child stunting remains inconclusive.

Stunting in children had also been marked by sex differences. Generally, boys were found to be more stunted than girls across Sub-Saharan Africa and other global regions, except for South Asia, where the opposite trend was observed (Baig-Ansari et al. 2006, Choudhury et al. 2016, Wamani et al. 2007). These findings were likely rooted in biological and social determinants. Biological phenomena has suggested that male fetuses and newborns are more sensitive to environmental factors and that females may be naturally selected during pregnancy, which was consistent with the lower stunting prevalence observed among girls across countries (DiPietro and Voegtline 2017, Stevenson et al. 2000).

Gender discrimination against girls, including female infanticide and neglect of female infants has been widely documented through excess mortality and morbidity of girls in China and India (Coale and Banister 1994, Khera et al. 2014, Nayak 2014). In Sub-Saharan Africa, gender discrimination also exists but social factors like female labor participation, polygamy, and bride prices could reduce adverse outcomes (Alkema et al. 2014, Seguino and Were 2013). Globally, males tended to be more prone to early life mortality and evidence overall lower survival rates as compared to females in early life (Hill and Upchurch 1995). Instead, female disadvantage tends to accumulate after the first five years of life (Alkema et al. 2014). Over the life cycle, females survive longer, on average, with longer life expectancy as compared to males globally (World Health Organization 2016). We examined child sex with stunting to examine whether sex differences occurred between stunting outcome and maternal characteristics.

Study Objectives

We hypothesized that short stature and underweight in mothers was associated with child stunting. We examined whether differences by sex of the child in stunting outcome differed and expected that males would be more stunted than females. Finally, we hypothesized that child HAZ would increase with higher maternal height and BMI.

Methods

The Demographic and Health Surveys (DHS) are national, cross-sectional data collected using a two-stage, probability cluster sampling design to enumerate households including women, men, and children 0-59 months old (Central Statistical Office, Ministry of Health Zambia and ICF International 2014). For this study, the Madagascar and Zambia DHS surveys were selected due to their completeness of child anthropometry data, and location in the Eastern Sub-Saharan African region. The most recent Madagascar DHS survey (MDHS) collected 17,857 households from November 2008 to August 2009 while the Zambia DHS (ZDHS) collected 15,920 household surveys from August 2013 to April 2014 (Central Statistical Office, Ministry of Health Zambia and ICF International 2014, National Institute of Statistics Madagascar and ICF Macro 2010). Response rates among households were 96% in Madagascar and 98% in Zambia. A total of 12,686 Malagasy and 13,517 Zambian children aged 0-59 months were enumerated. Anthropometric height and weight data were collected for 4,861 Malagasy mother-child pairs (39% of total) and 11,407 Zambian mother-child pairs (84% of total) (ibid).

We analyzed mothers and their children in Madagascar and Zambia from the DHS. We investigated whether associations existed between child stunting with maternal characteristics of height stature and body mass index status. We also explored whether these associations differed by child gender. Our outcomes on stunting and child height was defined in two ways. Our first analyses examined associations with child stunting using height-for-age z-score (HAZ) cut-points defined as non-stunted (HAZ > -2) or stunted (HAZ ≤ -2) status (World Health Organization 2004b). Our second analyses examined increases or decreases in continuous HAZ score to explore changes in height attainment.

Our main independent variables included maternal stature using height cut-offs (normal height ≥ 145 cm vs. short height <145 cm) and maternal nutritional status using BMI cutpoints (normal, overweight, underweight). Maternal short stature had been associated with adverse child outcomes but is an understudied topic in stunting (Arendt, Singh and Campbell 2018). Maternal BMI has implications with poor birth and neonatal outcomes, which could also be related to stunting development (Rahman et al. 2015). We stratified our summary statistics and regression models by child sex and examined if any differences existed between male and female children with maternal characteristics.

Covariates used in the analyses included household wealth quintiles (richest, richer, middle, poorer, and poorest), child birthweight status (normal vs. low), child dietary diversity status (adequate vs. inadequate), and birth order (first child, second child, and third child or beyond). The covariates were chosen to represent theoretically and statistically relevant variables. Household wealth was a known confounder in maternal health status and child stunting. Wealth quintiles were constructed from principal components analyses (PCA) of household wealth measures for each respective country with the top two quintiles designated as the wealthiest and wealthy quintiles. Prior literature also suggested that low child birthweight (below 2.5 kg) and inadequate dietary diversity also confounded the relationship between maternal height and nutritional status with child stunting (Rah et al. 2010). Child dietary diversity was a measure of child nutritional adequacy, which might also confound the main outcomes and exposures. Dietary diversity was categorized using standards of whether the child ate foods from seven possible food groups; inadequate dietary diversity was defined as consuming foods from less than four of these groups (Ruel and Arimond 2004). Finally, birth order was included as a covariate because past studies suggested potential differences in child health outcomes based on the child's sex and disadvantages with increasing birth order (Jayachandran and Pande 2017). Birth order was categorized into whether the child was born to their mother as a first, second, or later child.

Our statistical analyses reported odds ratios (OR) for child stunting using binary logistic regression models and changes in HAZ using linear regression models. Before model selection, we analyzed variables individually by performing cross-tabulations, tetrachoric correlations, univariate analyses, and Pearson correlations to understand potential statistical issues of our underlying assumptions. We built separate models to determine specific odds of stunting between maternal height, HAZ, BMI and later adjusted them for covariates. We also split these models into male and female stratifications to examine any sex differences on stunting outcome and maternal characteristics.

We conducted multivariate logistic models on stunting with maternal height stature (normal height ≥ 145 cm vs. short height <145 cm) and maternal BMI (normal, overweight, underweight). Next, we added covariates to each model to adjust for confounding. Finally, we stratified the adjusted models by male and female child sex and observed differences. We reported the adjusted odds ratios for the full, male, and female models for each maternal characteristic.

After running the logistic models, we used the continuous measures of the same variables for multivariate linear regression models on height-for-age z-score outcome. We specifically analyzed whether increases in maternal height in centimeters and maternal BMI score were associated with changes in the child's HAZ. We reported the final adjusted coefficients. The linear regression model results were compared to the logistic models to detect whether certain maternal characteristics were associated with changes in height attainment but not stunting status. We assessed variable selection based on theoretical underpinnings, statistical model criteria of a 10% or greater change in coefficient estimate, and examined the -2 log likelihood model fit statistics. Data were analyzed using SAS 9.4 statistical software package (SAS Institute Inc., Cary, North Carolina).

Results

The mean age of children and mothers in our sample was 29.6 months and 28 years old in Madagascar, respectively, and 29.5 months and 29 years in Zambia. The proportion of male and female children were about equal for both countries (49.7% female in Madagascar, 49.9% female in Zambia). Child stunting rates were recorded at 48.6% in Madagascar and 39.9% in Zambia while mean child height-for-age z-scores were -1.77 in Madagascar and -1.57 in Zambia.

Few mothers had short stature (6.7% Madagascar, 1.9% Zambia) and mean heights were 153.3 cm in Madagascar and 158.4 cm in Zambia (Figure 5.1 and 5.2). More mothers in Madagascar were underweight (26.11%) versus overweight (4.9%) while in Zambia, more mothers were overweight (19.8%) versus underweight (8.6%). About half of households in both countries were considered poor (49.8% Madagascar, 48.3% Zambia). Close to 10% of children in both countries were born with low birthweight (11.3% Madagascar, 8.2% Zambia) and a majority had inadequate dietary diversity (84.4% Madagascar, 86.2% Zambia). More detailed descriptive statistics and correlation tables are found in the Appendix Tables 5A.1 to 5A.8.

We analyzed bivariate models between risk factors and outcomes of interest (Appendix Table 5A.9 and 5A.12). We conducted unadjusted and adjusted multivariate logistic regression models (Tables 5.1, 5.2, 5.3, 5.4) and multivariate linear regressions (Tables 5.5, 5.6, 5.7, 5.8). In Madagascar and Zambia, children with short statured mothers had double the odds of stunting compared to children with normal statured mothers, after adjusting for covariates (Madagascar: aOR = 2.07, 95% CI: 1.39, 3.08; Zambia: aOR = 2.66, 95% CI: 1.69, 4.20). We examined models stratified by male and female gender for stunting odds among children with short statured mothers. Females had higher stunting coefficients in Madagascar (males: aOR = 1.68, 95% CI: 0.94, 3.00; females: aOR = 2.48, 95% CI: 1.43, 4.30) and males had higher coefficients in Zambia (males: aOR = 2.93, 95% CI: 1.46, 5.89; females: aOR = 2.59, 95% CI: 1.41, 4.77) but in both countries, the 95% confidence interval had overlapping values.

We found that overweight in mothers was associated with lower stunting odds in Zambia (aOR = 0.82, 95% CI: 0.69, 0.97) but no association was found in Madagascar after adjusting for covariates. When we stratified overweight BMI mothers by child sex, we observed different coefficients between males and females but the confidence intervals overlapped (Madagascar males: aOR = 0.80, 95% CI: 0.43, 1.51, females: aOR = 1.37, 95% CI: 0.77, 2.45; Zambia males aOR = 0.96, 95% CI: 0.77, 1.21, females: aOR = 0.67, 95% CI: 0.52, 0.87). Underweight in mothers was associated with about 1.4 odds of stunting in both countries (Madagascar: aOR = 1.43, 95% CI: 1.12, 1.84; Zambia: aOR = 1.41, 95% CI: 1.13, 1.75). We observed different coefficients by child gender among children with underweight mothers but also observed overlapping confidence intervals in both countries (Madagascar males: aOR = 1.42, 95% CI: 0.99, 2.03, females: aOR = 1.48, 95% CI: 1.04, 2.10; Zambia males aOR = 1.28, 95% CI: 0.95, 1.73, females: aOR = 1.55, 95% CI: 1.12, 2.16).

Our linear regression analyses of child height-for-age z-score changes were associated with maternal height attainment. We found that every centimeter increase in mother's height resulted in higher child HAZ (Madagascar: adjusted β = 0.045, 95% CI: 0.028, 0.062; Zambia: adjusted β = 0.006, 95% CI: 0.003, 0.008). Higher maternal BMI was associated with higher child HAZ (Madagascar: adjusted $\beta = 0.057$, 95% CI: 0.022, 0.092; Zambia: adjusted $\beta = 0.029$, 95% CI: 0.015, 0.043).

Discussion

Nearly half of Malagasy and 40% of Zambian children were stunted, far exceeding the global child stunting average of 23%. Surprisingly, the overall prevalence of short statured mothers was low in both countries at 6.7% in Madagascar and 1.9% in Zambia. Maternal and child age, proportion of poor households, dietary diversity and child sex ratios were similar between Madagascar and Zambia. Malagasy women had higher proportions of poor maternal outcomes including higher percentages of short stature and underweight status compared to Zambian mothers. Similarly, Malagasy women had lower mean height, BMI, and HAZ compared to Zambian women. Conversely, Zambian mothers had more overweight statuses than Malagasy women. Underweight mothers far exceeded overweight among Malagasy women (26% underweight, 5% overweight) while the opposite trend was found among Zambian women (9% underweight, 20% overweight). These anthropometry trends reflected some of the economic differences between the two countries where Zambia is considered one of the fastest growing economies and may be experiencing a dual burden of both underweight and overweight adult populations (Central Statistical Office 2013, Jehn and Brewis 2009).

Child stunting among children in both countries was associated with short stature and underweight in mothers. Having a short stature mother was associated with double the odds of child stunting in both Madagascar and Zambia. Maternal stunted HAZ was also associated with child stunting but due to lack of a comparable population to assess standard HAZ for adult African women, we rely on the short stature definition instead. Finally, underweight in mothers was associated with increased stunting odds in both countries, but overweight in mothers was not associated with lower odds of stunting. Our findings were consistent with prior literature in different locations that linked short stature and underweight in mothers with child development (Child Health Epidemiology Reference Group Small-for-Gestational-Age/Preterm Birth Working 2015, Khatun et al. 2018). We contributed context to maternal and child populations in Madagascar and Zambia and our findings underscored the importance of maternal height attainment and nutritional status as potential determinants of child stunting.

When we stratified these adjusted models by child sex, we observed some differences between male and female children in stunting odds. In Madagascar, we observed higher odds of stunting among females with short statured mothers compared to male children. In Zambia, we found the opposite with higher odds of stunting among male children with short statured mothers compared to females. Underweight among Malagasy mothers was associated with increased odds of child stunting among girls only. In Zambia, overweight mothers were associated with lower odds of child stunting among girls while underweight status was associated with higher stunting odds among girls; no associations were reported with boys. Female children with low birthweight and inadequate dietary diversity consistently had higher odds of stunting than males in all models for both countries, suggesting possible sex differences in birth outcomes and nutrition. However, since confidence intervals in these sex stratifications overlapped, the effects of modification were unclear.

While birth order was a factor in child sex differences cited by other studies, we did not observe any association between children of different birth orders with stunting (Jayachandran and Pande 2017). Our findings did not establish any causal claims but associations were found on girls faring worse than boys among children with short statured mothers in Madagascar, but the opposite was found in Zambia where boys fared worse than girls. The finding that girls had higher odds of stunting in Madagascar was surprising given a recent meta-analysis using similar data that found male children in Sub-Saharan African are more likely to be stunted than female children (Wamani et al. 2007). The explanation for these sex differences is unclear and may be rooted in biological, social, and cultural determinants.

In our linear regressions of child HAZ, we found that increases in maternal height, HAZ, and BMI were associated with higher child height attainment. These trends were expected in our hypotheses since increased maternal anthropometry and better nutritional status would be associated with higher HAZ in children.

This study had notable strengths and limitations. Our limitations included the inability to establish temporality of events given the cross-sectional nature of the data, lack of genetic or biological data, lack of detailed nutritional assessments, and lack of a validated tool to assess maternal HAZ. Our strengths included the use of available anthropometry data, large sample size from the DHS, and reliable field measurements.

Overall, our findings matched our hypothesis that poor maternal anthropometry including short stature and underweight statuses would be associated with child stunting. These results supported the idea that stunting in mothers can result in their children being stunted although we cannot detail the mechanisms. This aim also supported our integrated conceptual model, which linked the lives and health of mothers with the development of their child. The intergenerational effect of maternal health on child stunting was likely rooted in genetic, socioeconomic, and social determinants. Our findings on child sex differences were surprising. While we hypothesized that males would be more stunted than females, we observed this trend in Zambia but the opposite in Madagascar. This merits further sex-specific studies and could indicate potential gender inequality or other unknown factors.

Conclusion

Our study found that short stature and underweight in mothers were associated with increased odds of child stunting, which supported an intergenerational link of height attainment between mothers and children. We also found differences across child sex and maternal anthropometry with higher stunting odds among female children in Madagascar and conversely, male children in Zambia.

Chapter 5 Results Tables

Table 5.1 Multivariate logistic regression of maternal stature on child stunting outcome in Madagascar in Aim 1

	Madagascar		Madagascar		Stratified - Male		Stratified - Female	
Characteristics	**Unadjusted**		**Adjusted**		**Adjusted**		**Adjusted**	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Mother's stature								
Normal (≥ 145cm) (ref)								
Short (< 145cm)	2.04	[1.61, 2.58]	2.07	[1.39, 3.08]	1.68	[0.94, 3.00]	2.48	[1.43, 4.30]
Covariates								
Household wealth quintile								
Richest (ref)								
Richer			1.52	[1.13, 2.04]	1.90	[1.24, 2.91]	1.28	[0.84, 1.95]
Middle			1.79	[1.30, 2.45]	1.76	[1.14, 2.70]	1.76	[1.10, 2.82]
Poorer			1.45	[1.03, 2.04]	1.38	[0.85, 2.23]	1.53	[0.94, 2.48]
Poorest			1.04	[0.73, 1.47]	1.24	[0.75, 2.03]	0.89	[0.53, 1.47]
Birthweight								
Normal (≥ 2.5kg) (ref)								
Low (< 2.5 kg)			1.46	[1.05, 2.02]	1.42	[0.84, 2.39]	1.65	[1.08, 2.54]
Child dietary diversity								
Adequate (ref)								
Inadequate			0.93	[0.72, 1.19]	0.92	[0.64, 1.30]	0.97	[0.67, 1.41]
Birth order								
First child (ref)								
Second child			0.91	[0.68, 1.22]	1.20	[0.79, 1.80]	0.68	[0.44, 1.05]

Third or more			1.17	[0.92, 1.50]	1.22	[0.86, 1.71]	1.15	[0.81, 1.64]

Table 5.2 Multivariate logistic regression of maternal stature on child stunting outcome in Zambia in Aim 1

	Zambia		Zambia		Stratified - Male		Stratified - Female	
Characteristics	**Unadjusted**		**Adjusted**		**Adjusted**		**Adjusted**	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Mother's stature								
Normal (≥ 145cm) (ref)								
Short (< 145cm)	2.72	[2.05, 3.60]	2.66	[1.69, 4.20]	2.93	[1.46, 5.89]	2.59	[1.41, 4.77]
Covariates								
Household wealth quintile								
Richest (ref)								
Richer			1.71	[1.36, 2.14]	1.85	[1.36, 2.52]	1.55	[1.10, 2.18]
Middle			1.82	[1.46, 2.27]	2.06	[1.52, 2.78]	1.55	[1.11, 2.17]
Poorer			2.00	[1.60, 2.51]	2.27	[1.66, 3.09]	1.78	[1.29, 2.48]
Poorest			2.55	[2.02, 3.20]	2.78	[2.04, 3.81]	2.3	[1.64, 3.22]
Birthweight								
Normal (≥ 2.5kg) (ref)								
Low (< 2.5 kg)			2.65	[2.14, 3.29]	2.56	[1.87, 3.50]	2.81	[2.09, 3.78]
Child dietary diversity								
Adequate (ref)								
Inadequate			0.87	[0.73, 1.04]	0.84	[0.66, 1.07]	0.93	[0.72, 1.21]
Birth order								
First child (ref)								
Second child			1.12	[0.93, 1.36]	1.08	[0.84, 1.39]	1.18	[0.89, 1.56]
Third or more			1.01	[0.87, 1.18]	0.98	[0.79, 1.20]	1.07	[0.85, 1.33]

Table 5.3 Multivariate logistic regression of maternal BMI status on child stunting outcome in Madagascar in Aim 1

	Madagascar		Madagascar		Stratified - Male		Stratified - Female	
Characteristics	**Unadjusted**		**Adjusted**		**Adjusted**		**Adjusted**	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Mother's BMI status								
Normal (18.5 ≤ BMI < 25) (ref)								
Overweight (BMI ≥ 25)	0.72	[0.55, 0.94]	1.05	[0.69, 1.61]	0.80	[0.43, 1.51]	1.37	[0.77, 2.45]
Underweight (BMI < 18.5)	1.39	[1.22, 1.58]	1.43	[1.12, 1.84]	1.42	[0.99, 2.03]	1.48	[1.04, 2.10]
Covariates								
Household wealth quintile								
Richest (ref)								
Richer			1.56	[1.16, 2.11]	1.97	[1.28, 3.02]	1.30	[0.85, 1.99]
Middle			1.78	[1.29, 2.45]	1.69	[1.09, 2.61]	1.82	[1.13, 2.92]
Poorer			1.48	[1.05, 2.09]	1.36	[0.84, 2.22]	1.63	[1.00, 2.65]
Poorest			1.07	[0.75, 1.52]	1.22	[0.74, 2.02]	0.93	[0.56, 1.55]
Birthweight								
Normal (≥ 2.5kg) (ref)								
Low (< 2.5 kg)			1.42	[1.03, 1.97]	1.41	[0.84, 2.38]	1.58	[1.03, 2.43]
Child dietary diversity								
Adequate (ref)								
Inadequate			0.92	[0.72, 1.19]	0.89	[0.63, 1.27]	0.99	[0.68, 1.43]
Birth order								
First child (ref)								
Second child			0.88	[0.66, 1.19]	1.17	[0.77, 1.76]	0.68	[0.44, 1.04]
Third or more			1.14	[0.90, 1.46]	1.19	[0.84, 1.69]	1.12	[0.79, 1.59]

Table 5.4 Multivariate logistic regression of maternal BMI status on child stunting outcome in Zambia in Aim 1

	Zambia		Zambia		Stratified - Male		Stratified - Female	
Characteristics	**Unadjusted**		**Adjusted**		**Adjusted**		**Adjusted**	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Mother's BMI status								
Normal (18.5 ≤ BMI < 25) (ref)								
Overweight (BMI ≥ 25)	0.68	[0.62, 0.75]	0.82	[0.69, 0.97]	0.96	[0.77, 1.21]	0.67	[0.52, 0.87]
Underweight (BMI < 18.5)	1.43	[1.25. 1.64]	1.41	[1.13, 1.75]	1.28	[0.95, 1.73]	1.55	[1.12, 2.16]
Covariates								
Household wealth quintile								
Richest (ref)								
Richer			1.70	[1.35, 2.14]	1.88	[1.38, 2.57]	1.51	[1.07, 2.13]
Middle			1.75	[1.39, 2.20]	2.05	[1.51, 2.80]	1.44	[1.02, 2.03]
Poorer			1.89	[1.49, 2.38]	2.26	[1.63, 3.11]	1.58	[1.12, 2.23]
Poorest			2.44	[1.92, 3.09]	2.86	[2.07, 3.96]	2.02	[1.42, 2.88]
Birthweight								
Normal (≥ 2.5kg) (ref)								
Low (< 2.5 kg)			2.64	[2.13, 3.28]	2.57	[1.88, 3.52]	2.80	[2.08, 3.77]
Child dietary diversity								
Adequate (ref)								
Inadequate			0.85	[0.71, 1.01]	0.82	[0.65, 1.05]	0.88	[0.68, 1.14]
Birth order								
First child (ref)								
Second child			1.16	[0.96, 1.40]	1.11	[0.87, 1.45]	1.21	[0.92, 1.61]
Third or more			1.04	[0.89, 1.21]	0.99	[0.80, 1.21]	1.11	[0.88, 1.39]

Table 5.5 Multivariate linear regression models of maternal height on child HAZ in Madagascar in Aim 1

	Madagascar		Madagascar		Stratified - Male		Stratified - Female	
Characteristics	**Unadjusted**		**Adjusted**		**Adjusted**		**Adjusted**	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Mother's height (cm)	0.046	(0.037, 0.055)	0.045	(0.028, 0.062)	0.052	(0.028, 0.076)	0.037	(0.013, 0.061)
Covariates								
Household wealth score			0.074	(-0.032, 0.181)	0.049	(-0.107, 0.205)	0.090	(-0.056, 0.235)
Birthweight			0.229	(0.067, 0.391)	0.258	(0.021, 0.496)	0.259	(0.037, 0.481)
Child dietary diversity score			-0.066	(-0.130, -0.002)	-0.035	(-0.130, 0.059)	-0.088	(-0.175, -0.001)
Birth order			-0.052	(-0.096, -0.009)	-0.063	(-0.125, -0.000)	-0.041	(-0.102, 0.019)

Table 5.6 Multivariate linear regression models of maternal height on child HAZ in Zambia in Aim 1

	Zambia		Zambia		Stratified - Male		Stratified - Female	
Characteristics	**Unadjusted**		**Adjusted**		**Adjusted**		**Adjusted**	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Mother's height (cm)	0.002	(0.001, 0.003)	0.006	(0.003, 0.008)	0.037	(0.026, 0.049)	0.004	(0.001, 0.007)
Covariates								
Household wealth score			0.292	(0.237, 0.346)	0.234	(0.156, 0.312)	0.303	(0.226, 0.381)
Birthweight			0.415	(0.335, 0.496)	0.411	(0.297, 0.525)	0.420	(0.306, 0.535)
Child dietary diversity score			-0.123	(-0.154, -0.093)	-0.111	(-0.154, -0.069)	-0.137	(-0.181, -0.094)
Birth order			-0.005	(-0.027, 0.017)	-0.017	(-0.048, 0.014)	-0.003	(-0.034, 0.028)

Table 5.7 Multivariate linear regression models of maternal BMI on child HAZ in Madagascar in Aim 1

	Madagascar		Madagascar		Stratified - Male		Stratified - Female	
Characteristics	**Unadjusted**		**Adjusted**		**Adjusted**		**Adjusted**	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Mother's BMI	0.051	(0.032, 0.070)	0.057	(0.022, 0.092)	0.074	(0.021, 0.126)	0.041	(-0.005, 0.088)
Covariates								
Household wealth score			0.056	(-0.056, 0.167)	0.021	(-0.142, 0.185)	0.080	(-0.072, 0.231)
Birthweight			0.246	(0.083, 0.409)	0.274	(0.035, 0.513)	0.277	(0.054, 0.501)
Child dietary diversity score			-0.063	(-0.128, 0.002)	-0.031	(-0.127, 0.065)	-0.086	(-0.174, 0.001)
Birth order			-0.056	(-0.100, -0.012)	-0.068	(-0.132, -0.005)	-0.043	(-0.104, 0.018)

Table 5.8 Multivariate linear regression models of maternal BMI on child HAZ in Zambia in Aim 1

	Zambia		Zambia		Stratified - Male		Stratified - Female	
Characteristics	**Unadjusted**		**Adjusted**		**Adjusted**		**Adjusted**	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Mother's BMI	0.052	(0.044, 0.060)	0.029	(0.015, 0.043)	0.025	(0.006, 0.045)	0.030	(0.012, 0.051)
Covariates								
Household wealth score			0.255	(0.196, 0.314)	0.255	(0.173, 0.337)	0.258	(0.174, 0.343)
Birthweight			0.406	(0.324, 0.487)	0.434	(0.319, 0.549)	0.411	(0.296, 0.526)
Child dietary diversity score			-0.121	(-0.152, -0.091)	-0.107	(-0.149, -0.064)	-0.136	(-0.179, -0.092)
Birth order			-0.010	(-0.033, 0.012)	-0.013	(-0.045, 0.018)	-0.011	(-0.042, 0.021)

CHAPTER 6: AIM 2 – HOUSEHOLD SANITATION AND HYGIENE

Abstract

Introduction: Stunting is a global issue that affected 151 million children in 2017. Recent studies implicated environmental enteric dysfunction (EED), an inflammatory intestinal disorder resulting in malabsorption, in child stunting through consistent exposure to poor sanitation.

Methods: We analyzed cross-sectional data of 4,861 mother-child pairs from the 2008-2009 Madagascar and 11,407 mother-child pairs from the 2013-2014 Zambia Demographic and Health Surveys. Our outcomes were child stunting (HAZ $\leq$ -2) and height-for-age z-scores. Our main exposures of interest included children living in households without advanced flush toilets, piped drinking water source, and type of floor material. We also explored potential intermediaries and related exposures implicated in EED including household ownership of certain animals (cattle, chickens, pigs), sharing toilets with other households, treating drinking water, and recent diarrhea reports. We controlled for covariates including wealth, mother's education, urban/rural location, and child's age.

Results: Over forty-percent of children under five in our study sample were stunted. In both countries, not having piped water in the household (MDHS: aOR = 2.28, 95% CI: 1.19, 4.36, ZDHS: aOR = 1.95, 95% CI: 1.56, 2.44) and not having finished flooring was associated with increased stunting odds (MDHS: aOR = 1.53, 95% CI: 1.27, 1.85; ZDHS: aOR = 1.16, 95% CI: 1.02, 1.33). Households without an advanced flush toilet was associated with stunting in Zambia (aOR = 1.50, 95% CI: 1.25, 1.79). We found mixed results for intermediaries and co-exposures with stunting risk. We found potential effect measure modification between stunting and piped water use in Madagascar among households that did not treat their water (MDHS: aOR = 5.07, 95% CI: 1.47, 17.54) compared to those that treated their water (MDHS: aOR= 1.41, 95% CI: 0.63, 3.15). Height-for-age z-scores yielded results consistent with stunting outcome for each main sanitation exposure with lower HAZ.

Discussion: We observed high prevalence of stunting among Malagasy and Zambian children. Households lacking piped water and finished flooring were most closely associated to child stunting. Owning an advanced flush toilet and related sanitation exposures like sharing a toilet or treating drinking water had different effects on stunting, varying by country. Our findings provide population-level evidence for sanitation-related exposures in potential pathways towards stunting, consistent with recent clinical studies.

Introduction

Child stunting, or linear growth faltering, affected an estimated 22.2% of children under five globally, totaling 151 million, with the highest burden in low- and middle-income countries (UNICEF, WHO and World Bank Group 2018). For decades, clinicians and researchers considered stunting to be a form of chronic malnutrition yet nutritional interventions failed to resolve the condition (Dewey and Adu-Afarwuah 2008). Researchers began to examine other etiologies in stunting and discovered intestinal issues that led to “leaky guts” and malabsorption of nutrients (Dewey and Mayers 2011, Korpe and Petri 2012). This anomaly was termed environmental enteric dysfunction (EED) and is an autoimmune response that blunts small intestinal villi and leads to permeable membranes and reduced nutritional intake (Guerrant et al. 2013, National Institutes of Health 2016). Other complications of EED include reduced intestinal function, infection susceptibility, and decreased oral vaccine efficacy (Dewey and Mayers 2011, Korpe and Petri 2012).

EED is typically onset through repeated exposures to pathogens, most commonly through oral-fecal pathways including water and food sources, lack of sanitation infrastructure, animal contamination, or poor hygiene behaviors (Dewey and Mayers 2011, George et al. 2015a, Prendergast and Humphrey 2015). EED was posited as a mediator between adequate nutritional intake and child stunting by affecting small intestinal function and may also secondarily lead to growth hormone suppression (Crane, Jones and Berkley 2015, Korpe and Petri 2012, Prendergast and Humphrey 2015). Diagnosing EED had been challenging since the most accurate determination was made by biopsy, which were invasive, expensive, and impractical for many settings (Korpe and Petri 2012). Researchers have instead relied on biomarkers like dual sugar absorption tests to examine intestinal permeability (Denno et al. 2014). Even these biomarker tests are still impractical for assessing global EED risk among millions of children. This study explored more upstream EED risk factors by examining household access to water, sanitation, and hygiene resources and possible associations with stunting outcome.

Removing an individual from unsanitary conditions appeared to be the only known relief from EED, as evidenced in studies of adult migrants moving between low to high sanitation environments (Baker and Mathan 1968, Keusch et al. 2013, Lindenbaum, Gerson and Kent 1971). However, overhauling national sanitation infrastructure is onerous and slow and researchers have attempted to explore community-based sanitation and hygiene interventions as EED solutions (Arnold et al. 2013, Humphrey et al. 2015). These recent cluster-randomized control trials of nutrition with WASH (water, sanitation and hygiene) interventions reported disappointing null results in reducing stunting (Gladstone et al. 2019, Luby et al. 2018, Null et al. 2018). The role of proper sanitation in child stunting is more complex than previously thought and investigations need to redefine potential stunting solutions.

While the scientific consensus confirmed that poor sanitation leads to EED and stunting, no specific definition or level of sanitation has been established as a threshold to reduce stunting (Humphrey et al. 2015, Spears, Ghosh and Cumming 2013). For example, researchers were unsure whether an intermediate toilet like a covered pit latrine would significantly reduce stunting risk compared to a poor toilet source like open defecation. The recent randomized trials that had null outcomes specifically focused their interventions on a combination of: chlorinated water, latrines (creation or improvement), hygiene behaviors (safe stool disposal, handwashing, soap use, food preparation), nutrition (lipid based supplements and nutritional education), and health services (child health, immunizations, disease prevention) (Luby et al. 2018, Null et al. 2018, Prendergast et al. 2019). A recent article suggested that these null interventions were not misguided but rather the threshold to alleviate stunting might require the highest levels of sanitation, water infrastructure, and socioeconomic resources defined as indoor flush toilet, piped water into a household, and high-quality flooring (Husseini et al. 2018). Future interventions and research may need to consider flushed toilets instead of pit latrines and piped water into households instead of chlorinated tablets in order to improve stunting (ibid).

Study Objectives

This study examined whether the highest level of toilet type, drinking water source, and household floor materials was associated with child stunting. Our findings have implications for future studies and interventions in redefining adequate quality of toilets, drinking water, and floor materials. We used Madagascar and Zambia data on children under five and their mothers. Stunting was our main outcome of interest and is defined by height-for-age z-score (HAZ) cut-points with either non-stunted (HAZ > -2) or stunted (HAZ ≤ -2) status. Our second outcome was to explore changes in HAZ as a continuous measure. Our exposures of interest included drinking water source, toilet type, floor material, animal ownership, and water treatment. We categorized these exposures (Table 6.1) based on the highest quality sources (advanced flush toilets, piped water, and finished floor materials) versus all other sources, consistent with a recent study suggesting that good or intermediate sources are not adequate to resolve stunting (Husseini et al. 2018). First, we hypothesized that lacking the highest quality toilet and drinking water source would be associated with increased stunting odds and decreased height-for-age z-scores while highest quality sources would decrease odds of stunting and improve HAZ. Second, we hypothesized that related exposures like basic floor materials, household animal ownership, diarrhea, and lack of water treatment would be associated with stunting and low HAZ.

Methods

The Demographic and Health Surveys (DHS) were cross-sectional, nationally collected data on health topics in low- and middle-income countries. Surveys were collected using a two-stage, probability cluster sampling design enumerating households including women, men, and children 0-59 months old. For this study, Madagascar and Zambia DHS surveys were selected due to their completeness of child anthropometry data, GPS coordinates, and location in the Eastern Sub-Saharan African region. The most recent Madagascar DHS survey (MDHS) collected 17,857 households from November 2008 to August 2009 while the Zambia DHS (ZDHS) collected 15,920 household surveys from August 2013 to April 2014 (Central Statistical Office, Ministry of Health Zambia and ICF International 2014, National Institute of Statistics Madagascar and ICF Macro 2010). Response rates among households were 96% in Madagascar and 98% in Zambia. A total of 12,686 Malagasy and 13,517 Zambian children aged 0-59 months were enumerated. Anthropometric height and weight data were collected for 4,861 Malagasy mother-child pairs (39% of total) and 11,407 Zambian mother-child pairs (84% of total) (ibid).

Our outcomes on stunting and child height were defined in two ways. Our first analyses examined associations with child stunting, defined by WHO Child Growth Standards using height-for-age z-score cut-points (World Health Organization 2004b). Non-stunted children had HAZ > -2 while stunted children had HAZ ≤ -2. Our second analyses examined increases or decreases in HAZ score, a continuous measure, to explore height attainment regardless of stunting status. Higher HAZ equates to increased height attainment compared to the standard z-score while lower HAZ corresponded to lower height attainment.

Our exposures were categorized based on Husseini (2018)'s study that suggested only the highest thresholds of household toilet, drinking water, and flooring quality would be associated with stunting decline. Highest quality drinking water source was defined as piped water at the household and we dichotomized this into whether a household had piped drinking water into their dwelling. Highest quality toilet types were defined as flush toilets into a septic tank or sewer and we dichotomized this into whether a household had either flush toilet. Highest quality household floor materials included several definitions of finished flooring and we similarly dichotomized this variable (Florey and Taylor 2016). For other exposures, we included household ownership of animals linked to EED, treatment of drinking water, and recent child diarrhea in our models (George et al. 2015b). Please see Table 6.1 for detailed classifications of each exposure variable.

Table 6.1 Coding of household toilet, drinking water, and floor categories using DHS interview responses in Aim 2

Best toilet and drinking water sources versus all else		
Variable	**Yes**	**No**

Advanced flush toilets	Flush to piped sewer system Flush to septic tank	Flush to pit latrine Flush to somewhere else Flush to don't know where Ventilated improved pit latrine Pit latrine with or without slab No facility/bush/field Composting toilet Bucket toilet Hanging toilet
Piped drinking water source	Piped into dwelling	Piped to yard/plot Public tap/standpipe Tube well or borehole Protected well Unprotected well Protected spring Unprotected spring River/lake/ponds/stream/canal Rainwater Tanker truck Cart with water tank Bottled water
Highest quality floor materials	Parquet Polished wood Vinyl Asphalt strips Ceramic tiles Cement Carpet	Wood planks Palm Bamboo Mat Earth Sand Dung

Note: Any other or missing responses from DHS were classified as missing in the new variables
Source: (Florey and Taylor 2016, Husseini et al. 2018)

Covariates used in the analyses included household wealth (top two wealth quintiles), child's age (under or above 24 months of age), maternal education (above or below secondary school attainment), and urban or rural location. Wealth quintiles were constructed by the DHS from principal components analyses of household wealth measures for each respective country with the top two quintiles designated as the wealthiest and wealthy quintiles. Child age categories were designated based on differing growth trajectories in the WHO growth standards between children aged 0-23 months and 24-59 months, which would affect stunting diagnosis.

Our statistical analyses reported odds ratios (OR) for child stunting using binary logistic regression models and changes in HAZ using linear regression models. Before model selection, we analyzed variables individually by performing cross-tabulations, tetrachoric correlations, univariate analyses, and Pearson correlations to understand potential statistical issues of our underlying assumptions. Since toilet, water, and floor sources were correlated, we built separate models to examine their associations with stunting. We also included variables that were theoretically relevant to each main sanitation exposure but were not main expsoures. For example, in our flush toilet model, we included whether this toilet was shared with other households. Our piped drinking water model included whether households treated drinking water and our finished flooring model included whether child diarrhea was reported.

Multivariate logistic models on stunting were conducted using a model for each of the three main exposures of water (piped water source versus other sources), toilet (flush toilet to septic tank or sewer system versus all else), and floor material sources (finished floor materials versus other materials). Next, exposures with theoretical significance like intermediaries or effect measure modifiers for stunting were examined in each of these models including ownership of any sanitation-linked animals (cattle, chickens, pigs), any treatment of drinking water (yes or no), and any reported child diarrhea in the past two weeks (yes or no). We reported odds ratios for these unadjusted exposure models. Finally, we added covariates based on the literature and improvement of model fit including location type (urban or rural), child age (above or below 24 months), wealthy household classification (yes or no), and mother's education status (above or below secondary school completion). We reported the adjusted odds ratios after controlling for covariates.

After running the logistic models, we used the same variables for multivariate linear regression models to look for changes in height-for-age z-score coefficients. The linear models of exposure assessments were reported as unadjusted coefficients and after adjusting for covariates, we reported the final adjusted coefficients. The linear regression model results were compared to the logistic models. We investigated whether changes in HAZ might be detected in cases where no change in stunting status was found. Overall, we assessed variable selection based on theoretical underpinnings, statistical model criteria of a 10% or greater change in coefficient estimate, and examined the -2 log likelihood model fit statistics. Data were analyzed using SAS 9.4 statistical software package (SAS Institute Inc., Cary, North Carolina).

Finally, we conducted sensitivity analyses based on more traditional categorizations of quality toilet types, drinking water sources, and floor materials. We used a binary categorization for our main models of highest quality source versus all other sources. The categorizations in our sensitivity analyses were developed by the Joint Monitoring Programme of WHO and UNICEF that defined toilet types and drinking water into improved and unimproved sources (WHO and UNICEF 2017).

Results

Among all households in our study sample, about one-third were considered wealthy (32.3% Madagascar, 29.6% Zambia) and most were located in rural areas (81.9% Madagascar, 63.0% Zambia). The mean age of children and mothers in our sample were 29.6 months and 28 years old in Madagascar, respectively, and 29.5 months and 20 years in Zambia. Some mothers had at least a secondary level education (20.5% Madagascar, 33.2% Zambia) but most did not with the average education attainment was 3.2 years in Madagascar and 6.0 years in Zambia.

Child stunting rates in our study sample were 48.6% in Madagascar and 39.9% in Zambia. The mean child height-for-age z-score was -1.77 in Madagascar and -1.57 in Zambia. When examining our main exposures, we found that very few households had access to flush toilets connected to septic tanks or sewer systems (2.0% Madagascar, 8.5% Zambia) or piped water into their household (1.5% Madagascar, 5.1% Zambia). However, some households had high quality flooring (21.8% Madagascar, 34.5% Zambia). Descriptive statistics were detailed in Appendix Tables 6A.1 and 6A.2, tetrachoric correlation matrixes in Appendix Tables 6A.3 & 6A.5, and Pearson correlation matrixes in Appendix Tables 6A.4 & 6A.6.

First, we conducted bivariate logistic and linear regressions for both the MDHS and ZDHS (Appendix Tables 6A.7 and 6A.8) to understand unadjusted associations between single exposures and covariates with our outcomes. Next, we ran unadjusted and adjusted multivariate logistic regression models on the binary outcome on child stunting (Tables 6.2, 6.3, 6.4) and multivariate linear regression models on child height-for-age z-score (Tables 6.5, 6.6, 6.7).

In Madagascar, households without an advanced flush toilet had higher odds of stunting compared to children with advanced flush toilets but these associations were not significant after controlling for covariates. In Zambia, households without advanced flush toilets had higher odds of stunting even after controlling for covariates (aOR = 1.50, 95% CI: 1.25, 1.79). In both countries, children that lived in households lacking piped water into their homes had double the odds of stunting (Madagascar: aOR = 2.28, 95% CI: 1.19, 4.36, Zambia: aOR = 1.95, 95% CI: 1.56, 2.44) as compared to children with piped drinking water sources. We also observed that children living in households without finished flooring had higher odds of stunting in Madagascar (aOR = 1.53, 95% CI: 1.27, 1.85) and Zambia (aOR = 1.16, 95% CI: 1.02, 1.33).

Households that shared a toilet with other homes was linked to higher odds of stunting in Madagascar (aOR = 1.32, 95% CI: 1.09, 1.59) but not in Zambia. Household ownership of animals potentially linked to EED (cattle, chickens, pigs) was associated with increased stunting odds in Zambia when examined with piped water access (aOR = 1.11, 95% CI: 1.02, 1.21) and finished flooring (aOR = 1.11, 95% CI: 1.01, 1.20) but not flush toilet access. Reports of recent child diarrhea was associated with stunting in Zambia (aOR = 1.29, 95% CI: 1.16, 1.43) but not in Madagascar nor in other exposure models. We did not find treatment of drinking water associated with stunting in either country after adjusting for covariates. However, when we stratified piped water models by whether a household treated their drinking water, we found differences in Madagascar between the odds of stunting and piped water use among households that did not treat their water (MDHS: aOR = 5.07, 95% CI: 1.47, 17.54) compared to households that treated their water (MDHS: aOR= 1.41, 95% CI: 0.63, 3.15).

In our multivariate linear regression models in Madagascar, we observed a negative trend between HAZ and not having a flushed toilet or piped drinking water source but neither of the associations held after controlling for covariates. In Zambia, we found lower HAZ among children in households without flush toilets (β = -0.406, 95% CI: -0.534, -0.273) and piped water (β = -0.700, 95% CI: -0.848, -0.552) in their households after adjusting for covariates.

We also found that children in households without finished flooring had decreased child HAZ in both countries (Madagascar: β = -0.374, 95% CI: -0.547, -0.201; Zambia: β = -0.143, 95% CI: -0.242, -0.043). Lower HAZ was also associated with reported child diarrhea (Madagascar: β = -0.206, 95% CI: -0.400, -0.014; Zambia: β = -0.211, 95% CI: -0.291, -0.131). We did not observe an association between HAZ and sharing a toilet with other households. Household ownership of certain animals (cattle, chicken, pigs) were not associated with HAZ differences after controlling for covariates except in Madagascar when examining household floor material (Madagascar: β = 0.127, 95% CI: 0.006, 0.249). For household treatment of drinking water, no associations were found in Zambia but a paradoxical positive increase in HAZ was associated with no water treatment in Madagascar (Madagascar: β = 0.163, 95% CI: 0.029, 0.298).

For sensitivity analyses, we performed logistic regression models on WHO and UNICEF categorizations of toilet type and drinking water sources into binary categories (improved or unimproved) to compare whether this more inclusive classification of quality were associated with stunting (WHO and UNICEF 2017). We found that the main definitions of highest quality versus all other sources were adequate and had more associations with stunting than the binary classifications (Appendix Table 6A.9 and 6A.10). We also conducted sensitivity analyses on indicators of dietary diversity, disaggregated ownership of individual animal types (pigs, cattle, chickens), and shared toilet status as an effect measure modifier but did not discover any meaningful effects on stunting and excluded these in our final models.

Discussion

We observed high stunting rates among children in both of our study samples, which far exceeded the global average of 22.2% and underscored the magnitude and urgency in resolving stunting in Madagascar and Zambia. We found that height-for-age z-score coefficients were largely consistent with our logistic models on stunting outcome where higher stunting odds generally matched lower HAZ scores.

Children living in households without piped drinking water was the factor most highly associated with stunting with nearly double the odds of stunting and lower HAZ in both countries. Interestingly, there was possible evidence of effect measure modification in Madagascar between odds of stunting and piped water use depending on whether a household treated their drinking water, but the findings were unclear since confidence intervals overlapped. We found much higher stunting odds in Malagasy homes that did not treat their drinking water and did not have piped water compared to those that treated their water even in the absence of piped water infrastructure. This finding may support the importance of treating drinking water. However, we did not observe this trend in Zambia.

When we examined access to advanced flush toilets, we found that households without flush toilets were associated with higher stunting and lower HAZ in Zambia. We observed similar trends in Madagascar, but these findings were not significant after controlling for covariates. Lacking high-quality, finished floor materials in both countries were associated with higher odds of stunting and lower HAZ scores, which suggests that contamination from household flooring was a strong potential factor in stunting through elevated EED risk, which was supported by a study on child ingestion of soil (George et al. 2015b).

Ownership of animals that were linked to higher EED risk (cattle, chickens, pigs) were found to be inconsistently associated with stunting and height attainment in our study despite previous evidence in the literature (George et al. 2015a). One reason could be that children living in households with animals might benefit from the higher socioeconomic attainment conferred by animal despite being exposed to higher levels of contamination; further studies are needed to establish any links. When we examined recent diarrhea as an associated risk factor, we find increased stunting odds only among Zambian children and lower HAZ in both Malagasy and Zambian children. The role of diarrhea in stunting risk was unclear since it may act as an intermediary between EED and stunting or as a confounder. Other investigators had considered diarrhea to be the “tip of the iceberg” in stunting and not a direct causal factor (Prendergast and Humphrey 2015).

When we compared whether exposures were consistent between Madagascar and Zambia, we found differences between stunting and HAZ attainment between the two populations. In Madagascar, households without piped water, lacking finished flooring, and potentially sharing a toilet were associated with increased odds of stunting while in Zambia, households lacking a flush toilet, piped water, finished flooring, and recent diarrhea were associated with increased odds of child stunting. Madagascar and Zambia had differing economic development statuses. Higher proportions of Malagasies lived below the poverty line (72%) as compared to Zambians (61%) and less Malagasy households had sanitation facilities (12%) compared to Zambian households (44%) (Central Intelligence Agency 2017b, United Nations Development Programme 2016). These country-level differences, particularly the severe lack of sanitation in Madagascar, may have explained why we did not observe decreased stunting with flush toilets due to the high proportion of households lacking any toilet.

Overall, our findings matched our hypotheses that lacking the highest quality toilet, drinking water source, and floor materials were associated with stunting and lower HAZ. Our results also generally supported a recent study that suggested needing the highest quality water, sanitation, and other sources to alleviate stunting (Husseini et al. 2018). Similarly, our general findings of associations between toilet types, water, flooring, animal ownership, hygiene, and similar factors matched many hypotheses and findings of previous EED studies (Crane, Jones and Berkley 2015, George et al. 2015a, George et al. 2015b).

We explored an understudied population of children and women in Madagascar and Zambia. To our knowledge, this study is among the first population-level studies for EED risk factors in stunting risk. There were notable limitations in this study including the use of cross-sectional data, which could not ascertain temporality on whether exposures occurred before the outcome. Since DHS questionnaires were respondent-based, there could be underreporting or inaccurate data as compared to true behavior. Additionally, the actual quality of toilet and drinking water systems likely differed. For example, piped water sources could have been just as contaminated as a less advanced source, depending on the community and infrastructure. Our study also lacked biomarkers to diagnose EED and biological samples to measure actual contamination levels in the water, soil, or stools. Our study instead inferred potential risk of EED and odds of stunting using environmental factors.

Conclusion

In conclusion, our study presented population-level associations between inadequate toilets, poor drinking water sources, floor materials, and related exposures with child stunting and height attainment. These findings supported the broader research on EED risk factors in stunting, particularly in low- and middle-income settings.

Chapter 6 Results Tables

Table 6.2 Multivariate logistic regression models of child stunting on household access to advanced flush toilets in Madagascar and Zambia in Aim 2

	Madagascar		Madagascar		Zambia		Zambia	
Variables	**Unadjusted**		**Adjusted***		**Unadjusted**		**Adjusted***	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Flush toilet in household								
Yes (ref)								
No	1.95	[1.26, 3.03]	1.35	[0.85, 2.12]	2.03	[1.73, 2.38]	1.50	[1.25, 1.79]
Ownership of cattle, chicken or pigs								
Yes (ref)								
No	0.81	[0.67, 0.97]	0.98	[0.80, 1.20]	1.00	[0.92, 1.09]	1.09	[0.99, 1.20]
Share toilet								
No (ref)								
Yes	1.22	[1.02, 1.47]	1.32	[1.09, 1.59]	1.02	[0.93, 1.11]	1.07	[0.98, 1.17]

*Adjusted for household wealth, mother's education level, urban/rural location, and child age category

Table 6.3 Multivariate logistic regression models of child stunting on piped water household use in Madagascar and Zambia in Aim 2

	Madagascar		Madagascar		Zambia		Zambia	
Variables	**Unadjusted**		**Adjusted***		**Unadjusted**		**Adjusted***	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Piped water in household								
Yes (ref)								
No	2.70	[1.44, 5.07]	2.28	[1.19, 4.36]	2.53	[2.04, 3.13]	1.95	[1.56, 2.44]
Ownership of cattle, chicken or pigs								
Yes (ref)								
No	0.97	[0.84, 1.13]	1.07	[0.91, 1.26]	1.00	[0.93, 1,08]	1.11	[1.02, 1.21]
Treat drinking water								
Yes (ref)								
No	0.89	[0.77, 1.02]	0.86	[0.75, 1.00]	1.07	[0.98, 1.17]	0.98	[0.90, 1.07]

*Adjusted for household wealth, mother's education level, urban/rural location, and child age category

Table 6.4 Multivariate logistic regression models of child stunting on households with finished flooring in Madagascar and Zambia in Aim 2

Variables	Madagascar Unadjusted		Madagascar Adjusted*		Zambia Unadjusted		Zambia Adjusted*	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Finished flooring								
Yes (ref)								
No	1.46	[1.27, 1.68]	1.53	[1.27, 1.85]	1.52	[1.39, 1.65]	1.16	[1.02, 1.33]
Ownership of cattle, chicken or pigs								
Yes (ref)								
No	1.02	[0.90, 1.16]	1.06	[0.93, 1.21]	1.07	[0.98, 1.16]	1.11	[1.01, 1.20]
Diarrhea in last 2 weeks								
No (ref)								
Yes	0.97	[0.79, 1.19]	1.13	[0.92, 1.40]	1.20	[1.08, 1.33]	1.29	[1.16, 1.43]

*Adjusted for household wealth, mother's education level, urban/rural location, and child age category

Table 6.5 Multivariate linear regression models of height-for-age z-score on flush toilet availability in the household in Madagascar and Zambia in Aim 2

Variables	Madagascar Unadjusted		Madagascar Adjusted		Zambia Unadjusted		Zambia Adjusted	
	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI
Flush toilet in household								
Yes (ref)								
No	-0.476	(-0.856, -0.097)	-0.177	(-0.560, 0.206)	-0.625	(-0.740, -0.510)	-0.406	(-0.534, -0.278)
Ownership of cattle, chicken or pigs								
Yes (ref)								
No	-0.114	(-0.278, 0.050)	0.036	(-0.138, 0.210)	-0.030	(-0.099, 0.040)	0.025	(-0.050, 0.100)
Share toilet								
No (ref)								
Yes	0.002	(-0.166, 0.169)	-0.061	(-0.227, 0.105)	0.022	(-0.049, 0.093)	-0.017	(-0.089, 0.055)

*Adjusted for household wealth, mother's education level, urban/rural location, and child age category

Table 6.6 Multivariate linear regression models of height-for-age z-score on piped water in the household in Madagascar and Zambia in Aim 2

	Madagascar		Madagascar		Zambia		Zambia	
Variables	**Unadjusted**		**Adjusted**		**Unadjusted**		**Adjusted**	
	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI
Piped water into household								
Yes (ref)								
No	-0.516	(-1.044, 0.012)	-0.459	(-0.996, 0.079)	-0.889	(-1.030, -0.746)	-0.700	(-0.848, -0.552)
Ownership of cattle, chicken or pigs								
Yes (ref)								
No	0.085	(-0.062, 0.232)	0.148	(-0.007, 0.302)	-0.018	(-0.078, 0.043)	0.063	(-0.003, 0.130)
Treat drinking water								
Yes (ref)								
No	0.153	(0.017, 0.288)	0.163	(0.029, 0.298)	0.107	(0.040, 0.173)	-0.042	(-0.109, 0.026)

*Adjusted for household wealth, mother's education level, urban/rural location, and child age category

Table 6.7 Multivariate linear regression models of height-for-age z-score on household floor material in Madagascar and Zambia in Aim 2

Variables	Madagascar Unadjusted		Madagascar Adjusted		Zambia Unadjusted		Zambia Adjusted	
	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI
Finished flooring								
Yes (ref)								
No	-0.289	(-0.421, -0.157)	-0.374	(-0.547, -0.201)	-0.363	(-0.430, -0.297)	-0.143	(-0.242, -0.043)
Ownership of cattle, chicken or pigs								
Yes (ref)								
No	0.102	(-0.015, 0.220)	0.127	(0.006, 0.249)	0.024	(-0.039, 0.087)	0.061	(-0.006, 0.128)
Diarrhea in last 2 weeks								
No (ref)								
Yes	-0.009	(-0.203, 0.184)	-0.206	(-0.400, -0.014)	-0.118	(-0.197, -0.038)	-0.211	(-0.291, -0.131)

*Adjusted for household wealth, mother's education level, urban/rural location, and child age category

CHAPTER 7: AIM 3 – ARMED CONFLICT EXPOSURE

Abstract

Introduction: Nearly one in six children globally live in a conflict zone, which are typically located in low- and middle-income countries. In these same regions, child growth stunting is also widespread and affects one-quarter of all children under five. Armed conflicts exacerbate conditions that influence stunting including food security, economic development, healthcare access, and infrastructure. We explored whether possible interactions existed between nearby conflicts and stunting in children. We also investigated whether conflicts that occurred during critical developmental periods like pregnancy and the first year of life affected stunting and growth differently.

Methods: We combined cross-sectional health data of 4,861 mother-child pairs from the 2008-2009 Madagascar and 11,407 mother-child pairs from the 2013-2014 Zambia Demographic and Health Surveys with 318 armed conflict event data in Madagascar and 889 armed conflict event data in Zambia from the Armed Conflict Location and Event Data Project (ACLED) database. Our outcomes were child stunting for the logistic models and height-for-age z-scores for the linear models. Our independent variable was whether mother-child pairs were exposed to an armed conflict event within 50km, 100km, or 250km of their households at critical developmental stages of pregnancy (10 months before child's date of birth) and first year of life (0-12 months of age). Our main models focused on conflicts at 100km distances and on the pregnancy and first year of life, but we conducted analyses on all combinations. We controlled for covariates including wealth, urban/rural location, low birthweight, and dietary diversity.

Results: Forty-percent of children in the study sample were stunted. In both countries, over 25% of households were located within 100km of an armed conflict event during pregnancy (27.0%

Madagascar, 41.0% Zambia) and over 30% during infancy (30.1% Madagascar, 51.1% Zambia). In Madagascar, conflicts that occurred within 100km was associated with increased odds of child stunting if the conflict occurred during pregnancy (aOR = 1.43, 95% CI: 1.13, 1.82). In Zambia, we found decreased stunting odds with conflicts that occurred within 100km during pregnancy (aOR = 0.82, 95% CI: 0.71, 0.96) and the first year of life (aOR = 0.84, 95% CI: 0.72, 0.98). When we disaggregated the types of armed conflicts, we found increased odds of stunting with fatal conflicts during pregnancy and the child's first year in Madagascar and decreased odds of stunting with riots/protests during pregnancy and battles and violence against civilians during the child's first year in Zambia. Height-for-age z-scores decreased with higher numbers of conflicts within 100km during pregnancy and the child's first year in Madagascar but increased with more conflicts in Zambia during pregnancy.

Discussion: Stunting was a prevalent issue in both countries. Many households in Madagascar and Zambia were potentially exposed to a nearby armed conflict event during pregnancy and the first year of life, which are critical development periods. In Madagascar, we found that increased odds of stunting were associated with armed conflicts occurring within 100km during pregnancy and if the conflicts had fatalities. In Zambia, we had counterintuitive findings with decreased stunting odds associated with any conflicts within 100km during pregnancy or the child's first year, riot/protests during pregnancy, and battles and violence against civilians during the child's first year of life. These inconsistencies in our findings, particularly in Zambia, may suggest issues in defining conflicts, overexposure to conflicts, or unknown confounding relationships, which supports the need for further research between stunting and disaggregated conflict data.

Introduction

A recent report estimates that 357 million children, about 1 in 6, live in a conflict zone (Bhutta et al. 2019, Save the Children International 2018). In the past two decades, armed conflicts have occurred in about 37% of countries with much of the burden in the lowest income nations (Devakumar et al. 2014). These violent events affected social, economic, and political institutions, which also disrupted infrastructure, crop production, government functions, and health delivery (World Health Organization 2002). One study even quantified the adverse health risks at an 8% increased mortality risk among infants born within 50 kilometers of an armed conflict (Wagner et al. 2018).

The instability associated with conflicts also intersects with child stunting, a chronic condition resulting in height deficits affecting 22.2% of children under five years (151 million total) (UNICEF, WHO and World Bank Group 2018). Stunting prevalence is highest in regions that may also be simultaneously experiencing conflicts (Wagner et al. 2018). Child stunting is a multifaceted condition rooted in nutritional, genetic, socioeconomic, sanitary, and other factors (Dewey and Begum 2011, Prendergast and Humphrey 2015). Armed conflicts can exacerbate already tenuous conditions leading to child stunting like food insecurity, weak economic stability, poor water and sanitation infrastructure, limited health care, and mental health consequences (Devakumar et al. 2014, Kadir, Shenoda and Goldhagen 2018, Kadir, Shenoda and Goldhagen 2019). Few studies have examined the links between armed conflicts with long-term effects like child stunting and much of the limited research has focused on case studies of displacement, psychological trauma, or child mortality (Kadir, Shenoda and Goldhagen 2019, Wagner et al. 2018). Furthermore, armed conflict research has been typically conducted using national-level data and with few studies that have explored disaggregated and localized conflicts (Akresh, Caruso and Thirumurthy 2014).

Armed conflicts severely affect women and children through potential lifelong and intergenerational physiologic and psychological repercussions (Devakumar et al. 2014, Rieder and Choonara 2012). These consequences may have differing effects depending on the life stage of a mother and child (Duque 2017). We applied the life course perspective where the timing of an event or exposure and stage of development could significantly impact long-term development (Black et al. 2017, Elder 1998). Pregnancy and the first year of life were considered a critical periods of child development (World Health Organization 2014). Stunting can be onset as early as *in utero*, persist in infancy, and worsen as a child ages with the optimal time to intervene recommended before age two (Prentice et al. 2013, Victora et al. 2010). Conflicts occurring during pregnancy and infancy have been associated with premature birth, low birth weight, malnutrition, infectious diseases, post-traumatic stress disorder, increased mortality, height decline, lower cognitive ability in children, and worse economic outcomes (Akresh, Caruso and Thirumurthy 2014, Duque 2017, Kimhi et al. 2010). The developmental stage of a child can influence the severity that an armed conflict may have on growth stunting and overall health.

In addition to developmental timing, the proximity and type of armed conflict could also affect women and children since conflicts are variable and diverse (Maystadt, Calderone and You 2014, Wagner et al. 2018). Nearby conflicts might disrupt a household and interrupt community resources more severely than conflicts located further away (Wagner et al. 2018). The type of conflict and related violence also varies from battles, riots and protests, violence against civilians, and whether there were fatalities (ACLED 2017). Overall, we add to the limited literature on disaggregated armed conflict events with child stunting. We also presented novel approaches in examining conflicts with stunting by using three different distance buffers and exploring critical developmental time periods.

Study Objectives

In this paper, we assessed whether proximity of conflicts exposures and the type of conflict during pregnancy (10 months prior to birth) and the first year of life (first 12 months of life) were associated with child stunting and height attainment in children using data from Madagascar and Zambia. Stunting was our main outcome of interest and was defined by height-for-age z-score (HAZ) cut-points with either non-stunted (HAZ > -2) or stunted (HAZ <= -2) status. Our second outcome was to explore changes in HAZ as a continuous measure. Our main exposure was whether mother and/or child exposure to armed conflict. We also assessed sub-exposures of conflict by fatalities and types of events. First, we hypothesized that increased frequency of conflict events near the household was associated with higher odds of stunting and lower HAZ attainment. Second, we hypothesized that exposure to conflict during pregnancy resulted in child stunting and lower HAZ scores.

Methods

The Demographic and Health Surveys (DHS) were cross-sectional, nationally collected data on health topics in low- and middle-income countries. We used DHS surveys, which enumerate women, children 0-59 months old, and household members using a two-stage, probability cluster sampling design. For this study, Madagascar and Zambia DHS surveys were selected due to their completeness of child anthropometry data, GPS coordinates, and location in the Eastern Sub-Saharan African region. The most recent Madagascar DHS survey (MDHS) collected 17,857 household surveys from November 2008 to August 2009 while the Zambia DHS (ZDHS) collected 15,920 household surveys from August 2013 to April 2014 (Central Statistical Office, Ministry of Health Zambia and ICF International 2014, National Institute of Statistics Madagascar and ICF Macro 2010). Response rates among households were 96% in Madagascar and 98% in Zambia. A total of 12,686 Malagasy and 13,517 Zambian children aged 0-59 months were enumerated. Anthropometric height and weight data were collected for 4,861 Malagasy mother-child pairs (39% of total) and 11,407 Zambian mother-child pairs (84% of total)

The Armed Conflict Location and Event Data Project (ACLED) was a comprehensive database of conflict events reported from news reports, civil society publications, human rights publications, and security updates. ACLED is the largest source of disaggregated conflict data and includes GPS coordinates, dates, fatalities reported, and type of conflict event. We used version 7 of the ACLED databases, spanning January 1997 to December 2016, on Madagascar and Zambia to match the MDHS and ZDHS, respectively. There were 875 total conflict events in Madagascar and 1,135 events in Zambia between 1997 to 2016 (Raleigh 2016). After removing ACLED conflicts that occurred after the DHS survey dates, we included a total of 318 events (36.3% of total) in Madagascar and 889 conflicts (78.3% of total) in Zambia. To further establish temporality and reduce migration bias, we only included women and children that have resided in their current residence at least during the pregnancy and child's reported age.

Our outcomes on stunting and child height were defined in two ways. Our first outcome of child stunting was defined by height-for-age z-score cut-points as defined by the WHO (World Health Organization) child growth standards (World Health Organization 2004b). Non-stunted children had HAZ > -2 while stunted children had HAZ ≤ -2. Our second outcome examined increases or decreases in HAZ score, a continuous measure, to explore height attainment regardless of stunting status. Higher HAZ equated to increased height attainment compared to the standard z-score, while lower HAZ corresponded to lower height attainment.

Figure 7.1. Illustration of conflicts that occur within 50km, 100km, or 250km buffer distances from a DHS household based on GPS coordinates

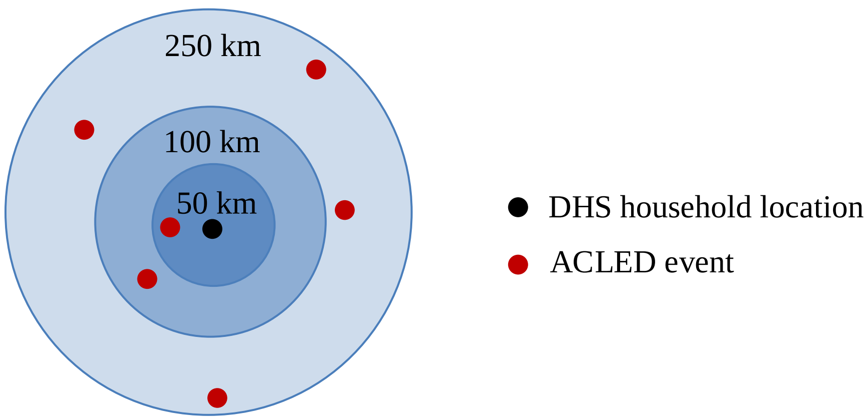
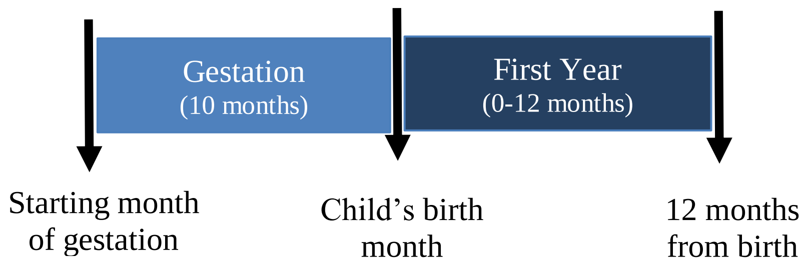


Figure 7.2. Diagram of two exposure time periods to armed conflicts during pregnancy and the first 12 months of life



Our main exposure was occurrence of armed conflicts near the household. We developed buffers, which were geographic radiuses surrounding a household GPS location, at 50km, 100km, and 250km distances (Figure 7.1). Next, we examined whether the GPS coordinates of reported ACLED conflict events fell within the household buffer. Among conflicts that fell within the household buffer, we then confirmed whether these conflicts occurred during two critical periods in the mother-child pair lifespan using available dates: 1) pregnancy: 10 months prior to the child's month of birth and 2) first year of life: between birth month to 12 months of age (Figure 7.2). In our analyses, we assessed all children in our sample for any conflicts that occurred during pregnancy but for the first year of life, we only include children 12 months or older, up to 59 months of age, to ensure temporality of the exposure before the outcome since stunting is a long-term condition. We counted the number of conflicts that occurred within a set buffer distance during each of these critical periods and dichotomized a variable to indicate whether a conflict occurred (yes or no). We also examined whether a specific type of conflict (battle, riots/protests, or violence against civilians) or whether a fatality occurred (yes or no) was associated with stunting outcome. We focused our analyses on the middle buffer at 100km and observed the 50km and 250km for comparison.

Our statistical analyses reported odds ratios (OR) for child stunting using binary logistic regression models and changes in HAZ using linear regression models. Before model selection, we analyzed variables individually by performing cross-tabulations, tetrachoric correlations, univariate analyses, and Pearson correlations to understand potential statistical issues of our underlying assumptions. Since the occurrence of conflicts was created based on the household GPS location and event dates, we ran separate multivariate logistic models for each combination of buffer distance (50km, 100km, 250km), sub-type of conflict (fatal, battle, riot/protest, or violence against civilians), and critical periods (pregnancy and first year of life). For example, we ran separate models on fatal conflicts that occurred 100km during the child's first year of life and battles that occurred within 50km during pregnancy.

Next, we added covariates based on the literature and improvement of model fit including location type (urban or rural), wealthy household classification (yes or no), birthweight (low or normal), and child dietary diversity (adequate or inadequate). We hypothesized that child stunting and armed conflict events would be confounded by location since ACLED events were concentrated near cities (Raleigh 2016). We included household wealth since wealthier families would have resources to both protect against conflict consequences and potentially prevent stunting as compared to poor households (Hegre, Østby and Raleigh 2009). Since low birthweight infants were associated with conflicts in prior studies, we also included this potential confounder (Akresh, Caruso and Thirumurthy 2014). Conflicts also disrupt food security and access to crops, which is also connected with stunting outcome so dietary diversity served as a proxy measure for child nutrition (Martin-Shields and Stojetz 2018, Ruel and Arimond 2004). For each logistic model, we reported the unadjusted and adjusted odds ratio after controlling for covariates.

After running the logistic models, we used continuous measures for each variable, typically the number of conflicts, for multivariate linear regression models to assess for changes in height-for-age z-score coefficients. We reported unadjusted and adjusted coefficients. The linear regression model results were compared to the logistic models on whether changes in HAZ might be detected in cases where no change in stunting status was found.

Overall, we assessed variable selection based on theoretical underpinnings, statistical model criteria of a 10% or greater change in coefficient estimate, and examined the -2 log likelihood model fit statistics. Geographic analyses were conducted in ArcGIS Desktop 10.5 and later merged with DHS data for statistical analyses (Environmental Systems Research Institute, Redlands, California). All statistical analyses were performed in SAS 9.4 (SAS Institute Inc., Cary, North Carolina).

Results

Among all households in our study sample, about one-third were considered wealthy (32.3% Madagascar, 29.6% Zambia) and most lived in rural areas (81.9% Madagascar, 63.0% Zambia). The mean age of children and mothers in our sample were 29.6 months and 28 years old in Madagascar, respectively, and 29.5 months and 20 years in Zambia. In our sub-sample of children over 12 months of age, the mean age of children were 36.3 months in Madagascar and 35.7 months in Zambia. Some mothers had at least a secondary level education (20.5% Madagascar, 33.2% Zambia) but most did not with the average education attainment was 3.2 years in Madagascar and 6.0 years in Zambia.

Child stunting rates in our study sample were higher than global averages (23.8%) with 48.6% stunted in Madagascar and 39.9% stunted in Zambia. The mean child height-for-age z-score was -1.77 in Madagascar and -1.57 in Zambia. We observed that during pregnancy and within 100km of households in Madagascar, 27.0% were exposed to any conflict, 14.8% were exposed to a fatal conflict, 5.8% were exposed to a battle, 23.4% were exposed to a riot/protest, and 25.4% were exposed to violence against civilians while in Zambia, 41.0% were exposed to any conflict within 100km of their household during pregnancy, 19.4% were exposed to a fatal conflict, 5.6% were exposed to a battle, 36.9% were exposed to a riot/protest, and 26.3% were exposed to violence against civilians. The mean number of conflicts within 100km in Madagascar was 1.1 conflicts during pregnancy and 1.1 during the first year while in Zambia, the mean was 3.6 conflicts during pregnancy and 4.5 in the first year.

During the first 12 months of life, and within 100km of a household in Madagascar, 30.1% of children were exposed to any conflict, 22.1% were exposed to a fatal conflict, 10.6% were exposed to a battle, 28.0% were exposed to a riot/protest, 27.5% were exposed to violence against civilians while in Zambia, 51.1% were exposed to any conflict within 100km of their household during infancy, 24.7% were exposed to a fatal conflict, 9.7% were exposed to a battle, 45.2% were exposed to a riot/protest, 34.8% were exposed to violence against civilians. We presented maps of each country with sub-regional overviews of child stunting, conflict locations, types of conflicts, and fatal conflicts (Figures 7.3, 7.4, 7.5, 7.6). The full descriptive statistics are detailed in the Appendix Tables 7A.1 and 7A.2.

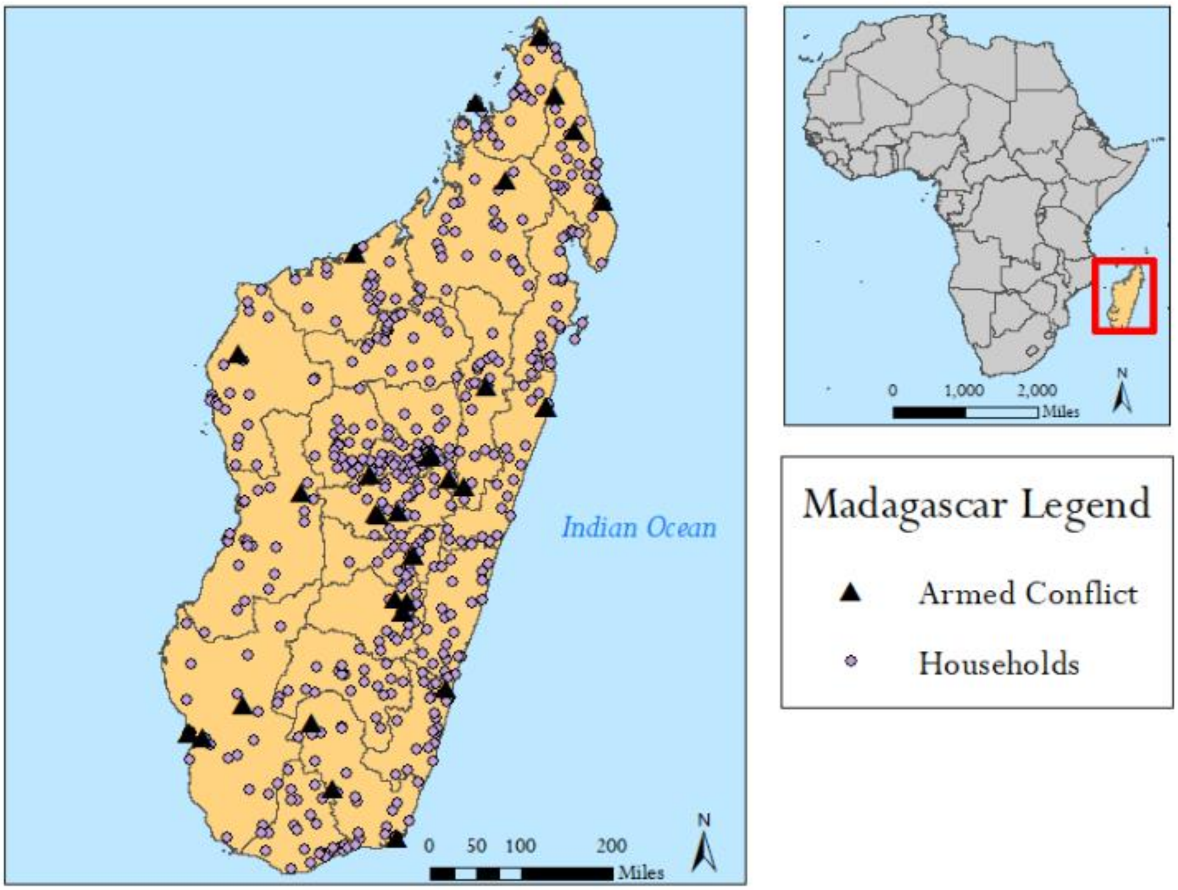
We assessed variables for collinearity using tetrachoric and Pearson correlation matrixes (Appendix Tables 7A.3 to 7A.5) and conducted bivariate logistic and linear regressions (Appendix Tables 7A.6 and 7A.7) to understand unadjusted associations between conflict exposures and covariates with our outcomes. Covariates were selected based on previous literature, theoretical understanding, and changes in coefficients. We included location type (urban or rural), wealthy household classification (yes or no), birthweight (low or normal), and child dietary diversity (adequate or inadequate) as our covariates. We ran multivariate logistic regression models on child stunting outcome during pregnancy (Tables 7.1) and the first year of life (Table 7.2) and adjusted for covariates. Multivariate linear regression models were created on child height-for-age z-scores with counts of conflicts during pregnancy (Tables 7.3) and first year of life (Table 7.4), adjusted for covariates.

In Madagascar, conflicts that occurred within 100km were associated with increased odds of child stunting if the conflict occurred during pregnancy (aOR = 1.43, 95% CI: 1.13, 1.82) but not during the first year of life. In Zambia, we found that conflicts within 100km were associated with decreased odds of stunting during pregnancy (aOR = 0.82, 95% CI: 0.71, 0.96) and first year of life (aOR = 0.84, 95% CI: 0.72, 0.98). When we explored whether the fatality or type of conflict mattered within the 100km radius, we found higher odds of stunting in Madagascar with fatal conflicts during pregnancy (aOR = 1.32, 95% CI: 1.00, 1.73) and fatal conflicts in the first year of life (aOR = 1.38, 95% CI: 1.02, 1.87). In Zambia, lower odds of stunting were found with riots/protests occurring within 100km during pregnancy (aOR = 0.79, 95% CI: 0.68, 0.93), battles during child's first year (aOR = 0.64, 95% CI: 0.50, 0.81), and violence against civilians during child's first year (aOR = 0.76, 95% CI: 0.65, 0.89).

In our multivariate linear regression models within 100km of Malagasy households, decreased HAZ was associated with any conflict during pregnancy (β = -0.038, 95% CI: -0.074, -0.003), fatal conflicts during pregnancy (β = -0.157, 95% CI: -0.360, -0.046), violence against civilians during pregnancy (β = -0.100, 95% CI: -0.193, -0.007), any conflict during the child's first year (β = -0.062, 95% CI: -0.109, -0.016), and violence against civilians during the child's first year (β = -0.130, 95% CI: -0.223, -0.036). We observed increased HAZ within 100km of Zambian households was associated with any conflicts during pregnancy (β = 0.015, 95% CI: 0.010, 0.020), fatal conflicts during pregnancy (β = 0.079, 95% CI: 0.021, 0.138), battles during pregnancy (β = -0.120 , 95% CI: -0.253, 0.014), riots/protests during pregnancy (β = 0.021, 95% CI: 0.012, 0.029), and violence against civilians during pregnancy (β = 0.065, 95% CI: 0.045, 0.084).

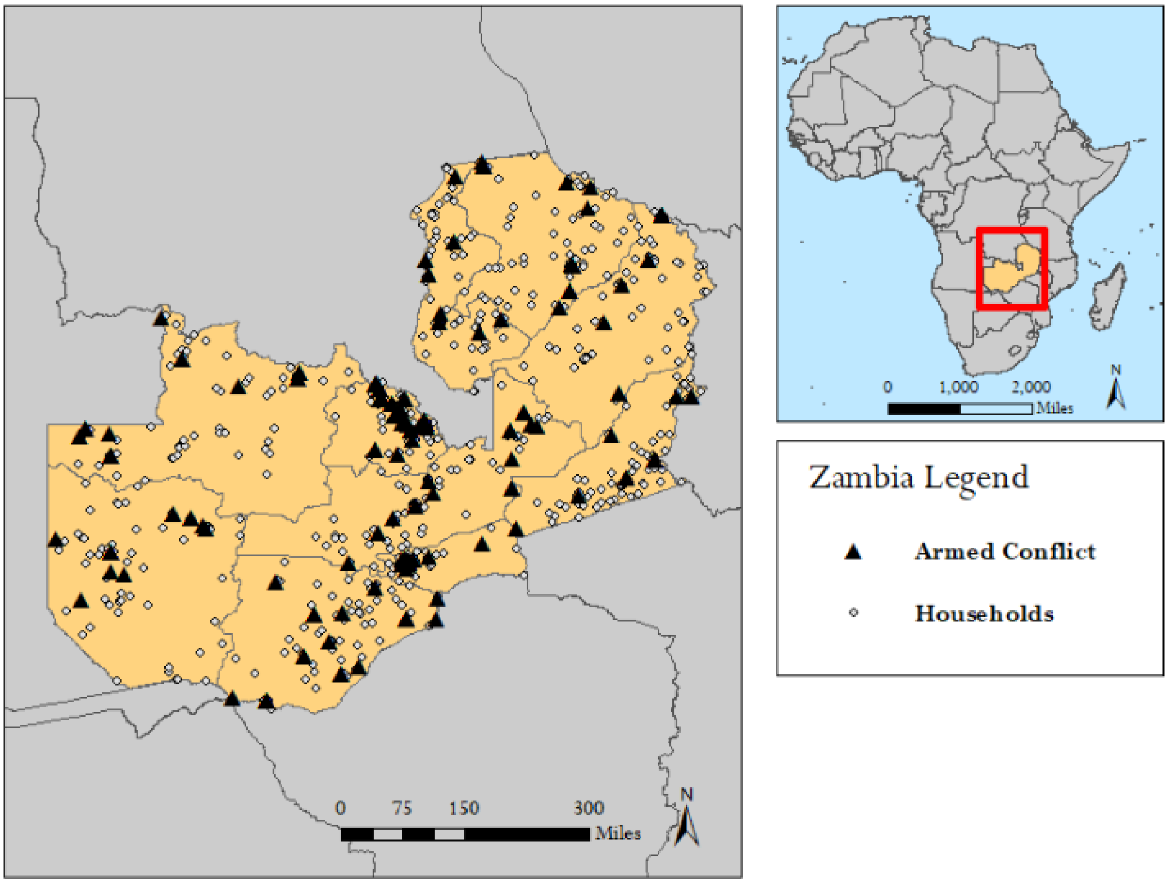
For sensitivity analyses, we performed logistic and linear regression models on households within 50km and 250km and found similar trends (Appendix Tables 7A.8 to 7A.11). We also analyzed whether conflicts in the first 24 months were associated with stunting but decided to exclude this timespan for comparability between the 10 months of pregnancy with the first 12 months of life. We also initially included mother's lifetime exposure to conflicts but excluded these analyses due to the limited timeframe of the conflict database and inability to ascertain conflicts before 1997.

Figure 7.3 Map of armed conflicts and child stunting in Madagascar 1997-2009



Data Source: Madagascar DHS 2008-2009, Madagasdcar ACLED v7, Map By: Stephanie Ly

Figure 7.4 Map of armed conflicts and child stunting in Zambia 1997-2014



Data Source: Zambia DHS 2013-2014, ACLED Zambia v7, Map By: Stephanie Ly

Figure 7.5 Map of armed conflicts types and fatalities in Madagascar 1997-2009

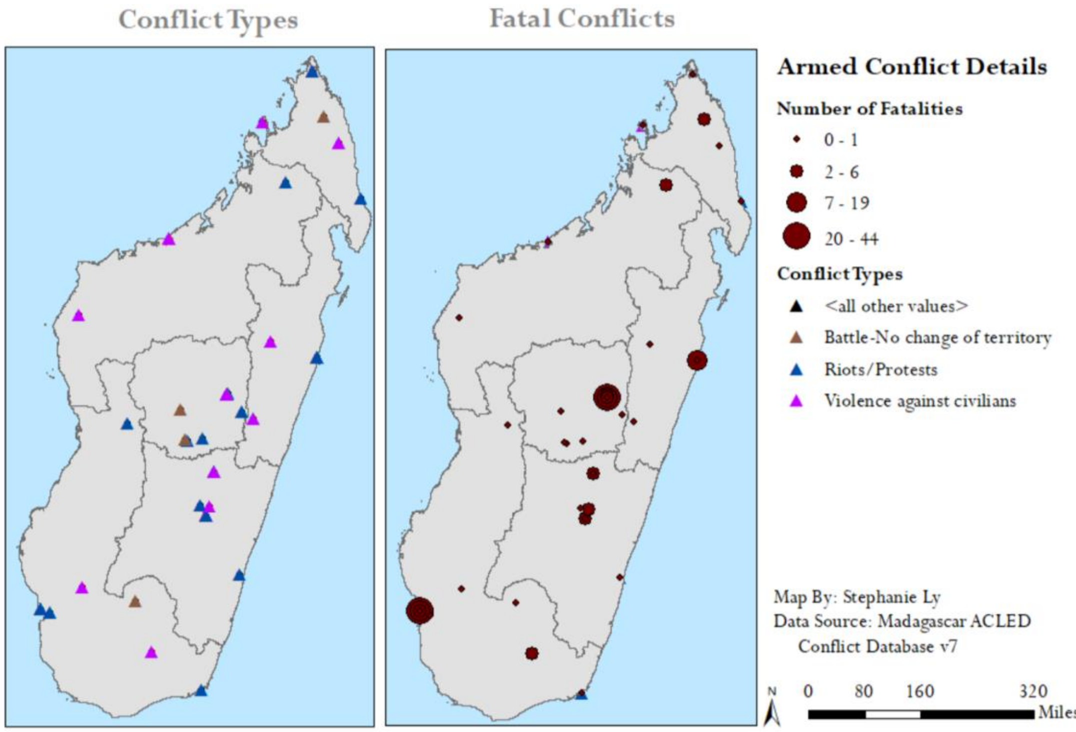
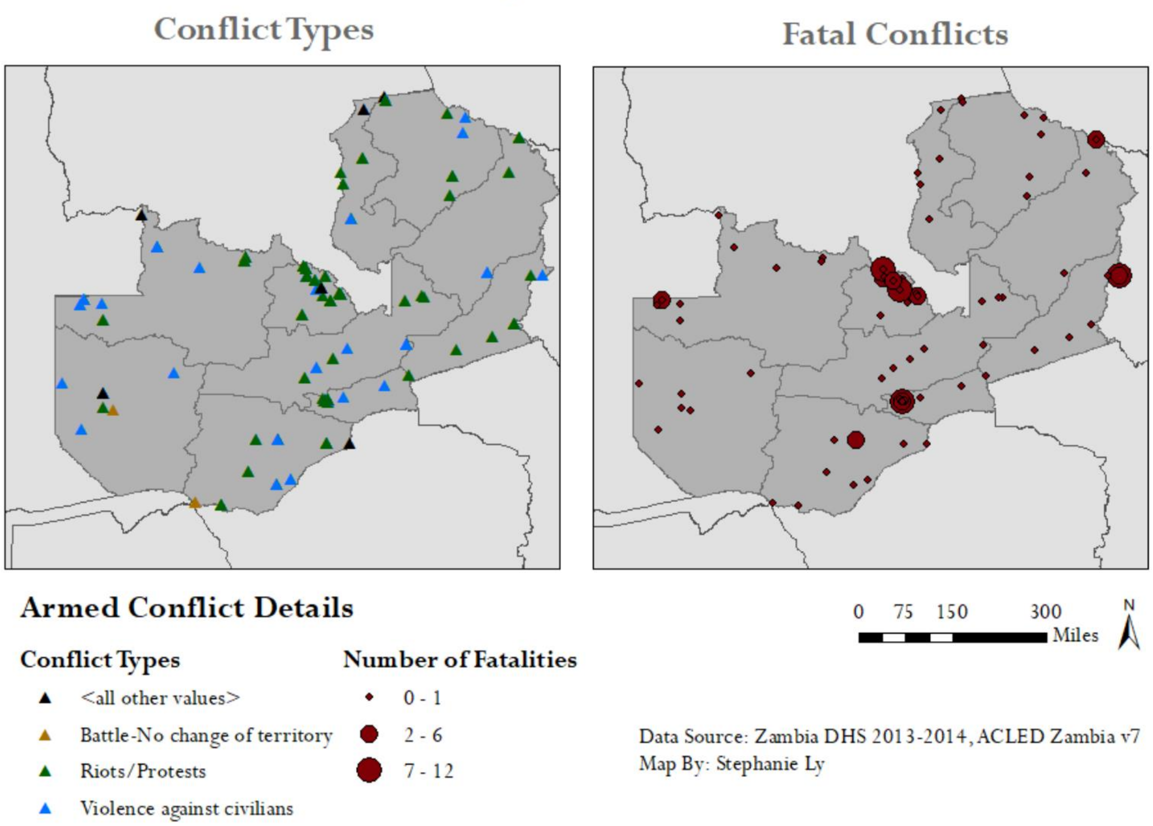


Figure 7.6 Map of armed conflicts types and fatalities in Zambia 1997-2014



Discussion

A large proportion of children in our study sample were stunted (40% or more) in both Madagascar and Zambia, which exceeded the global stunting rate of 22.2%. Equally alarming, was the proportion of study households that had experienced conflicts within 100km: 27.0% during pregnancy and 30.1% during the first year of life in Malagasy households and 41.0% during pregnancy and 51.1% during the first year in Zambian households. When we expanded the distance to 250km, these proportions increased to 58.4% during pregnancy and 63.7% during the first year in Madagascar and 78.9% during pregnancy and 88.2% during the first year in Zambia. In this study, we focused on armed conflicts that occurred within a 100km radius of the household to ascertain whether this mid-level distance was associated with child stunting, expanding on a recently conducted study that also used GPS coordinates at the household level (Wagner et al. 2018).

We hypothesized that exposures to conflicts near the household during pregnancy or first year of life would be associated with increased odds of child stunting. While our findings in Madagascar met these hypotheses, our findings in Zambia were contrary to predictions. In our adjusted multivariate models, conflicts in Madagascar were associated with increased risk of child stunting while in Zambia, conflicts were associated with a decreased stunting risk. When we further explored whether a specific type of conflict or associated fatalities were associated with stunting, we found that in Madagascar, the odds of stunting increased with fatal conflicts during pregnancy and the first year, but no association was found with types of conflicts. We also had counterintuitive findings of decreased stunting odds in Zambia with riots/protests during pregnancy and battles and violence against civilians during the child’s first year of life. These unexpected findings may be due to the limited or problematic conflict data and small number of event types. We may also have unknown differences between the types of conflicts in Madagascar and Zambia or variables that confound the relationship between stunting and types of conflicts. Since the literature was sparse on disaggregated conflict data on child stunting, we could not compare our findings to established research.

In our linear regression models, which examined the counts of conflicts with height-for-age z-scores, we expected to find higher numbers of conflicts associated with decreased HAZ. We observed this hypothesized finding in Madagascar within 100km with any pregnancy conflict reports, fatal conflicts during pregnancy, violence against civilians during pregnancy, any first-year conflicts, and violence against civilians during first year. We observed the opposite trend in Zambia where increased conflict events within 100km were associated with increased HAZ for any conflict, fatal conflicts, riots/protests, and violence against civilians during pregnancy. We noted that the same issues of limited conflict data, small number of sub-types of conflicts, and unknown confounders could be influencing these findings.

When we compared armed conflict exposures between Madagascar and Zambia, we observed many differences between the two study samples. Several factors may potentially explain these differing results between the two countries. First, there were more overall reported conflicts in Zambia (n=1,135) than in Madagascar (n=875) and consequently, a much higher number of households were exposed to conflicts in Zambia than in Madagascar. Second, we note that missing data may be biasing our results in Zambia since 35.4% of households at 100km were not eligible due to residency or date restrictions as compared to 12.0% in Madagascar. Third, our findings in Zambia where exposures to armed conflicts was associated with lower stunting risk and higher HAZ might be confounded and interlinked with other factors that are beneficial to the household or child. For example, high conflict zones were concentrated near urban areas, which could also increase food security or access to health care, or the sub-population is inherently different in these areas, but these suggestions are purely speculative and require further research. Finally, there could be differences in the quality of conflict reports between Madagascar and Zambia which would lead to these observed differences. There could be both reporting issues from the original data source or conflicts could represent differences between oppression or civilian empowerment in Zambia, but we do not have data to support these theories.

Our study had several strengths and limitations. Our limitations included the inability to confirm household self-reports of conflicts, ascertain mother's entire lifetime exposure to conflicts, level of personal harm or trauma due to each conflict, and broader effects of conflicts on health access or security. We also noted limits on specificity of the DHS data on both specific dates and GPS coordinates since event dates are reported using month and year and GPS coordinates were purposefully displaced to protect participant confidentiality. However, due to our use of gestation and the child's age in months as well as larger buffer zones, these specificity limitations should not have significantly biased the data. Our strengths included establishment of temporality using conflict and child birth dates, localized geographic data instead of country-level reports, disaggregated conflict information, and thorough health measures from the DHS. This study was among the few investigations to use GIS coordinates of households and explored the impacts on long-term child development. Our results were based on the available data and demonstrated the importance and inconsistency of armed conflict events on child development during critical life periods. Further research is needed to detail possible health care and interventions based on proximity of households and families to armed conflicts and the consequences of specific conflict events on the surrounding community.

Conclusion

In conclusion, our study contributed to the sparse literature on child stunting with disaggregated, household-level armed conflict exposures during critical developmental periods. We found that conflicts within 100km of a household during pregnancy were associated with increased odds of stunting in Madagascar and decreased odds in Zambia. We did not find any association with conflicts within 100km during the child's first year of life and subsequent stunting in Madagascar, but in Zambia, there was also an association of decreased odds of stunting. The specific type of conflict and risk of stunting remained unclear, but we observed differences in stunting association with fatal conflicts, battles, and violence against civilians. Our findings contained some anticipated hypotheses but also contained contradicting results. Further research is needed using primary data from households and their specific exposure and impact of conflicts.

Chapter 7 Results Tables

Table 7.1 Multivariate logistic regression models of armed conflict exposures within 100km during pregnancy and child stunting outcome in Madagascar and Zambia in Aim 3

	Madagascar Unadjusted		Madagascar Adjusted*		Zambia Unadjusted		Zambia Adjusted*	
Exposures	**Model 1**		**Model 2**		**Model 3**		**Model 4**	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Conflicts within 100km during pregnancy								
No (ref)								
Yes	1.37	[1.20, 1.57]	1.43	[1.13, 1.82]	0.80	[0.73, 0.88]	0.82	[0.71, 0.96]
Fatal conflicts within 100km during pregnancy								
No (ref)								
Yes	1.19	[1.01, 1.41]	1.32	[1.00, 1.73]	0.71	[0.65, 0.78]	0.87	[0.72, 1.04]
Battles within 100km during pregnancy								
No (ref)								
Yes	0.92	[0.69, 1.23]	0.89	[0.57, 1.39]	0.88	[0.72, 1.07]	0.94	[0.69, 1.26]
Riots/protests within 100km during pregnancy								
No (ref)								
Yes	1.20	[1.02, 1.41]	1.27	[0.97, 1.66]	0.78	[0.71, 0.86]	0.79	[0.68, 0.93]
Violence against civilians within 100km during pregnancy								
No (ref)								
Yes	1.16	[0.99, 1.36]	1.11	[0.85, 1.46]	0.77	[0.69, 0.85]	0.85	[0.72, 1.01]

*Adjusted for wealthy households, urban/rural location, low birthweight, and child dietary diversity

Table 7.2 Multivariate logistic regression models of armed conflict exposures within 100km during a child's first year and child stunting outcome in Madagascar and Zambia in Aim 3

Exposures	Madagascar Unadjusted Model 1		Madagascar Adjusted* Model 2		Zambia Unadjusted Model 3		Zambia Adjusted* Model 4	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Conflicts within 100km during child's first year								
No (ref)								
Yes	1.21	[1.04, 1.40]	1.23	[0.93, 1.62]	0.93	[0.84, 1.03]	0.84	[0.72, 0.98]
Fatal conflicts within 100km during child's first year								
No (ref)								
Yes	1.32	[1.11, 1.56]	1.38	[1.02, 1.87]	1.00	[0.89, 1.13]	0.95	[0.80, 1.13]
Battles within 100km during child's first year								
No (ref)								
Yes	1.06	[0.80, 1.41]	0.49	[0.29, 0.83]	0.84	[0.69, 1.01]	0.64	[0.50, 0.81]
Riots/protests within 100km during child's first year								
No (ref)								
Yes	1.15	[0.96, 1.38]	1.33	[0.97, 1.83]	0.95	[0.86, 1.06]	0.90	[0.77, 1.05]
Violence against civilians within 100km during child's first year								
No (ref)								
Yes	0.93	[0.77, 1.11]	1.01	[0.74, 1.39]	0.89	[0.80, 0.99]	0.76	[0.65, 0.89]

*Adjusted for wealthy households, urban/rural location, low birthweight, and child dietary diversity

Table 7.3 Multivariate linear regression models of armed conflict count within 100km during pregnancy and child height-for-age z-score in Madagascar and Zambia in Aim 3

	Madagascar Unadjusted		Madagascar Adjusted*		Zambia Unadjusted		Zambia Adjusted*	
Exposures	**Model 1**		**Model 2**		**Model 3**		**Model 4**	
	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI
Conflicts within 100km during pregnancy								
	-0.044	(-0.065, -0.022)	-0.038	(-0.074, -0.003)	0.019	(0.015, 0.023)	0.015	(0.010, 0.020)
Fatal conflicts within 100km during pregnancy								
	-0.119	(-0.232, -0.006)	-0.157	(-0.360, -0.046)	0.082	(0.051, 0.114)	0.079	(0.021, 0.138)
Battles within 100km during pregnancy								
	0.069	(-0.194, 0.331)	0.066	(-0.354, 0.485)	-0.014	(-0.094, 0.065)	-0.120	(-0.253, 0.014)
Riots/protests within 100km during pregnancy								
	-0.018	(-0.046, 0.010)	-0.011	(-0.056, 0.034)	0.027	(0.021, 0.033)	0.021	(0.012, 0.029)
Violence against civilians within 100km during pregnancy								
	-0.101	(-0.154, -0.048)	-0.100	(-0.193, -0.007)	0.074	(0.060, 0.089)	0.065	(0.045, 0.084)

*Adjusted for wealthy households, urban/rural location, low birthweight, and child dietary diversity

Table 7.4 Multivariate linear regression models of armed conflict count within 100km during a child's first year and child height-for-age z-score in Madagascar and Zambia in Aim 3

	Madagascar Unadjusted		Madagascar Adjusted*		Zambia Unadjusted		Zambia Adjusted*	
Exposures	**Model 1**		**Model 2**		**Model 3**		**Model 4**	
	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI
Conflicts within 100km during child's first year								
	-0.039	(-0.065, -0.014)	-0.062	(-0.109, -0.016)	0.005	(0.002, 0.008)	0.002	(-0.003, 0.006)
Fatal conflicts within 100km during child's first year								
	-0.186	(-0.290, -0.081)	-0.138	(-0.331, 0.055)	0.030	(-0.000, 0.061)	-0.002	(-0.062, 0.059)
Battles within 100km during child's first year								
	-0.066	(-0.300, 0.169)	0.583	(0.162, 1.000)	0.108	(0.034, 0.181)	0.165	(-0.010, 0.340)
Riots/protests within 100km during child's first year								
	-0.029	(-0.067, 0.009)	-0.036	(-0.105, 0.033)	0.007	(0.002, 0.012)	0.002	(-0.006, 0.010)
Violence against civilians within 100km during child's first year								
	-0.023	(-0.077, 0.031)	-0.130	(-0.223, -0.036)	0.021	(0.009, 0.034)	0.010	(-0.007, 0.028)

*Adjusted for wealthy households, urban/rural location, low birthweight, and child dietary diversity

CHAPTER 8: DISCUSSION, STRENGTHS/LIMITATIONS, IMPLICATIONS, & CONCLUSION

Discussion

The discussion of specific results of the three aims were detailed in previous chapters. In this chapter, we summarize the overall research and provide a general discussion. This dissertation contributed research related to both existing and emerging topics in child stunting, which moved beyond traditional approaches of stunting as solely a nutritional deficiency. The main objective was to examine associations between emerging factors with child height and stunting using two nationally representative Demographic and Health Survey data from Madagascar and Zambia. In Aim 1, maternal characteristics and child gender factors were explored with stunting and height attainment outcomes. In Aim 2, sanitation, water source, and floor materials were investigated for associations with stunting and height outcomes. In Aim 3, armed conflict events during critical developmental stages were examined in relation to child stunting and height. The findings in each aim confirmed the complex nature of stunting since no clear, single associated factor has emerged. While many of our hypotheses were confirmed, some were contradictory to what we had expected.

Stunting has been viewed through a biomedical lens in which the condition could be resolved with a specific medication or treatment (Lane 2014). This traditional approach is evident in failed interventions focused on specific and single solutions like micronutrients, supplemental feeding, deworming, or even an anti-inflammatory drug to resolve EED (Bhutta et al. 2008, Dewey and Adu-Afarwuah 2008, Jones et al. 2014). Some recently concluded cluster-randomized clinical trials combined nutrition plus sanitation interventions but had limited success in improving linear growth outcomes (Humphrey and et al. 2019, Luby et al. 2018, Null et al. 2018). Targeting a single factor like sanitation would be unlikely in mitigating widescale child stunting (Maleta and Manary 2019). Instead, approaching stunting through a holistic framework is necessary (Black et al. 2017).

This dissertation was guided by the Integrated Conceptual Model, which integrated the Life Course Perspective and Social Ecological Model, detailed in Chapter 3. The prominent themes included the concept of individuals embedded in larger structures, children are linked to the lives of their mothers, and the timing of events liked armed conflicts matter. The main goals of the integrated model were achieved in the three aims by examining child height dependency on maternal anthropometry, stunting influenced by external levels at the household and macro levels, and the interrelatedness of each aim in a complex structure. The dissertation made theoretical contributions in child stunting through the integrated model by highlighting: 1) intergenerational links through maternal outcomes, 2) multiple levels above and beyond individuals, 3) several interconnected paradigms, and 4) developmental timing.

Our findings in Aim 1 supported the linked lives concept of the Life Course Perspective where stunted children were associated with short-statured and underweight mothers. This aim focused on the individual level and the results supported the theory behind maternal anthropometry linked with child stunting. Aim 2 included the concepts of multiple levels beyond individuals and the interconnectedness of factors by adding household level factors with individual factors. We found that children in households with less-than-best water and sanitation sources were linked to stunting, which is a result of household, community, and external structures. Aim 3 included all levels from individual, household, community, and macro through the broad effects of armed conflicts on child stunting. In Aim 3, both concepts of timing and interconnectedness were integrated. The timing of an event during critical child development periods and the disruption of armed conflicts on interconnected social, economic, and governmental structures would influence child stunting. We found that exposure to some armed conflicts during pregnancy and a child's first year of life were associated with later stunting in Madagascar. However, we also had surprising findings in Zambia of armed conflict events associated with decreased odds of stunting, which suggested other unknown factors in the pathway or the potential benefits associated with locations near conflicts like increased access to resources.

Strengths and Limitations

The overall dissertation had several major limitations. The first limitation involved the use cross-sectional and respondent-based survey data from the DHS. The cross-sectional nature of the data limited establishment of temporality and causal inference. The DHS surveys relied on interviewer-led and respondent answers, which could have introduced recall or interviewer bias. The DHS surveys were also limited to established survey items and there was no ability to expand on questions related to child stunting.

The second limitation was the lack of biomarker data. To accurately diagnose EED, drinking water composition, or contamination of household floor materials, biological samples were necessary. In this dissertation, we relied on proxy measures for environmental exposures like animal ownership, drinking water source, toilet classification, and floor material type. This severely limited the ability to implicate unsanitary conditions with EED on the path to stunting.

The third limitation was the heterogeneity of armed conflict exposures on individuals. The ACLED database reported several types of conflicts from many sources. Each conflict event may have affected mothers and children differently depending on the disruptiveness of a conflict and whether the family was directly affected. The resulting trauma of an armed conflict and pathway to child stunting is complex and this dissertation was unable to explore these effects. This unmet area also presents an opportunity for further future research.

This dissertation had notable strengths in contributing novel approaches and information to the child stunting literature. The first strength was the use of nationally-representative data (Central Statistical Office, Ministry of Health Zambia and ICF International 2014, DHS Program 2017b, National Institute of Statistics Madagascar and ICF Macro 2010). The Madagascar and Zambia DHS data were among the most valid and reliable interviewer-led surveys within low- and middle-income countries (ibid). Both country datasets were representative at both local and national levels (DHS Program 2017b). The DHS study design, sampling, and methodology were well-documented and replicable with quality assurance measures. The ACLED databases were among the largest disaggregated sources of armed conflict micro-data (Raleigh 2016). The database contained details including responsible actors, classification of events, and GPS coordinates. Since ACLED gathered data from several sources, it captured conflict events that may not be formally recorded such as riots or protests. Furthermore, the database contained events dating back to 1997, which was one of the oldest conflict micro-data sources. ACLED allowed this dissertation to capture diverse types of conflicts and ascertain proximity to households.

The second strength included robust analyses for each research aim. Our regression models for each aim included both logistic regression on stunting outcome and linear regression on HAZ. We also conducted sensitivity analyses to test whether different definitions of our main variables differ. For example, since limited information existed for specific distances between an armed conflict and household, we tested different buffers and their interaction with main variables.

The third strength was our examination of diverse factors and association with child stunting by applying an integrated theoretical approach. We investigated maternal characteristics, child gender, sanitation factors, and armed conflicts exposures, expanded on studies that focused on few factors (Dewey and Adu-Afarwuah 2008). This dissertation was among the first studies to explore emerging areas including water and sanitation factors in EED and potential role of nearby armed conflicts in child stunting. Moreover, Madagascar and Zambia have been understudied in the child stunting literature. Future stunting research could integrate a holistic approach and utilize similar factors in examining stunting.

Implications

This dissertation has public health significance for child stunting research and interventions, which remains unresolved and complicated. The research aims and analyses had the following contributions for public health research and practice in stunting: 1) maternal and child interconnection, 2) disparities in socioeconomic attainment, 3) multiple risk factors, and 4) interventions at broader levels.

First, height attainment and health outcomes of mothers and children were interlinked, which was consistent with previous literature. Our findings showed that short-statured and underweight mothers were associated with stunted children. Prior research similarly suggested that stunted children turn into stunted adults and later give birth to stunted infants, continuing the intergenerational cycle (Addo et al. 2013, Martorell and Zongroneb 2012). There were likely many systemic factors acting at multiple levels to influence stunting in mothers and their children (Devakumar et al. 2014). To date, most stunting interventions had focused solely on the child while treatment of the mother or entire family could potentially lead to more impactful results (Dewey and Adu-Afarwuah 2008).

Second, socioeconomic status was a consistently associated factor between child stunting and the main independent factors in each research aim. Our primary definition of SES across the research aims included a wealth index adapted to the local context and maternal educational attainment. Children in higher SES households fared better, which matched the stunting literature (Aheto et al. 2015, Garcia et al. 2012). Since wealth was locally constructed in the DHS, we recognized that even the wealthiest children in Madagascar and Zambia would be disadvantaged compared to the average child in a high SES country (World Bank Group 2019). SES attainment influenced access to basic services and would likely interact with multiple levels.

Third, multiple risk factors were identified in stunting, which supports the concept of stunting as a complex issue. Our findings included associations between stunting with maternal characteristics, hygiene and sanitation, and armed conflict exposures. These results overlapped a mixture of social, familial, behavioral, and economic determinants (Black et al. 2017, Spears 2013). This dissertation was not meant to be a comprehensive search for all risk factors in stunting as there were likely many more outside of the aims. However, our studies highlighted the importance of factors that are currently understudied and underapplied in stunting research and practice.

Fourth, we posited that child stunting arose after broader external levels influenced the individual level. Our results indicated the associations of stunting with maternal health, sanitation infrastructure, and conflict proximity which were controlled by many external structures operating at the national, governmental, environmental, community, and interpersonal levels. These upstream influences could be better incorporated into future research studies and interventions by framing stunting as embedded in external structures and creating programs with both individual and broader strategies to prevent stunting (Black et al. 2017, Devakumar et al. 2014, Garcia et al. 2012).

This dissertation also had policy implications. Stunting remains a highly studied but unresolved condition affecting large proportions of children globally. Major civil society organizations and international donors have funded stunting initiatives and programs like the WHO, UNICEF, USAID (United States Agency for International Development), World Bank Group, and Bill and Melinda Gates Foundation, (Bill & Melinda Gates Foundation 2019, UNICEF, WHO and World Bank Group 2018, USAID 2014). The United Nations Sustainable Development Goals (SDGs) had even set Target 2.2 to end all forms of malnutrition, including stunting, by 2030 (United Nations 2019). While these organizations do not legislate, they undeniably influence policies and funding directions in countries and programs, respectively. If civil society and foundations highlighted the importance of resolving stunting using a multifactor and broader approach, this may positively influence policies and interventions.

Conclusion

This dissertation advanced the literature on child stunting by examining maternal characteristics, water and sanitation factors, and armed conflict exposure. Child stunting affected a large proportion of the world's children with the highest concentration in under resourced regions. We focused on Madagascar and Zambia to examine cross-sectional and nationally representative data to contribute a population-level analysis of stunting factors. The studies sought to understand individual height attainment and stunting outcome within broader structures across differing factors. We found several factors associated with stunting including maternal height and nutritional status, drinking water source, household floor material type, and armed conflict exposure. This research aimed to expand the focus of stunting etiology and interventions from single treatments or nutritionally-focused efforts into broader programs addressing multiple factors and levels.

APPENDIX

Supplemental Tables

Figure 5A.1 Descriptive map of short statured women and child stunting in Madagascar 2008-2009

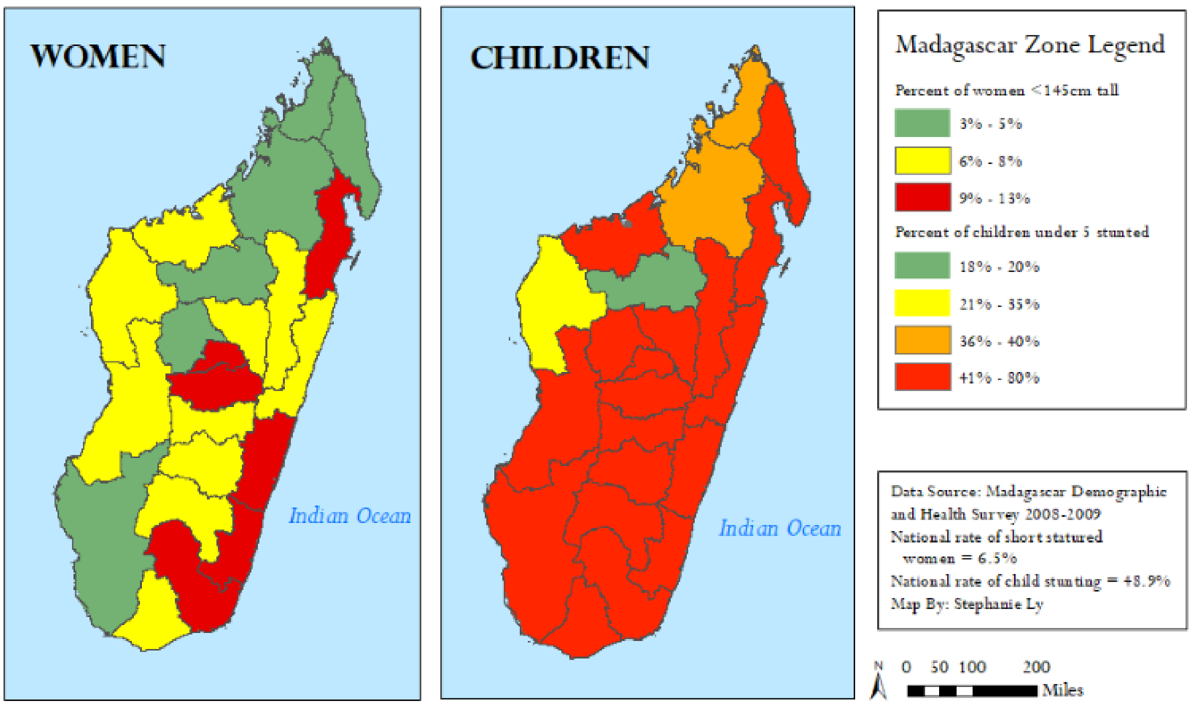


Figure 5A.2 Descriptive map of short statured women and child stunting in Zambia 2013-2014

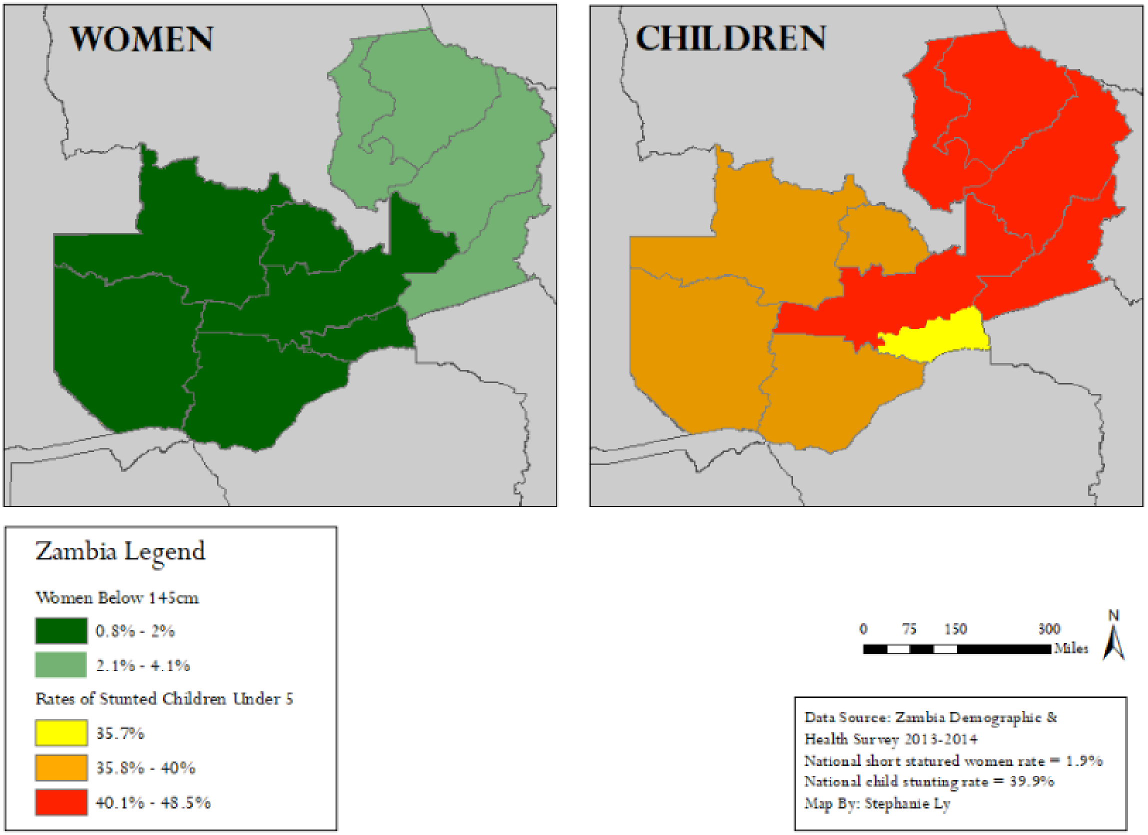


Table 5A.1 Descriptive characteristics of maternal anthropometry and sex of the child in the MDHS stratified on stunting status in Aim 1

Madagascar DHS 2008-2009 Maternal and Child Characteristics Stratified by Stunting Status			
Predictors	**Non-Stunted** (n = 2,501)	**Stunted** (n = 2,360)	**Total** (n = 4,861)
Sex of the child by stunting status			
Male	1184 47.3%	1261 53.4%	2445
Female	1317 52.7%	1099 46.6%	2416
Total	2501	2360	4861
Mother short stature <145cm by stunting status			
Normal stature	2372 95.4%	2141 91.1%	4513
Short stature	114	210	324

	4.6%	8.9%	
Total	2486	2351	4837
Mother BMI status by stunting status			
Underweight	567 22.8%	694 29.5%	1261
Normal	1772 71.4%	1564 66.6%	3336
Overweight	144 5.8%	91 3.9%	235
Total	2483	2349	4832
Covariates	**Non-Stunted** (n = 2,501)	**Stunted** (n = 2,360)	**Total** (n = 4,861)
Wealth index by stunting status			
Poorest	737 29.5%	655 27.8%	1392
Poorer	503 20.1%	525 22.3%	1028
Middle	409 16.4%	445 18.9%	854
Richer	382 15.3%	428 18.1%	810
Richest	470 18.8%	307 13.0%	777
Total	2501	2360	4861
Low birthweight by stunting status			
Normal	947 90.5%	782 86.6%	1729
Low birthweight	99 9.5%	121 13.4%	220
Total	1046	903	1949
Child Dietary Diversity Adequacy by Stunting Status			
Inadequate	1731 84.7%	1583 84.0%	3314
Adequate	312 15.3%	302 16.0%	614
Total	2043	1885	3928
Birth order of child			
First child	604 24.2%	501 21.2%	1105
Second child	507 20.3%	430 18.2%	937
Third or more child	1390 55.6%	1429 60.6%	2819
Total	2501	2360	4861

Table 5A.2 Descriptive characteristics of maternal anthropometry and sex of the child in the ZDHS stratified on stunting status in Aim 1

Zambia DHS 2013-2014 Maternal and Child Characteristics Stratified by Stunting Status			
Predictors	**Non-Stunted** (n = 6,858)	**Stunted** (n = 4,549)	**Total** (n = 11,407)
Sex of the child by stunting status			
Male	3305 48.2%	2416 53.1%	5721
Female	3553 51.8%	2133 46.9%	5686
Total	6858	4549	11407
Mother short stature <145cm by stunting status			
Normal stature	6775 98.9%	4407 97.0%	11182
Short stature	77 1.1%	136 3.0%	213
Total	6852	4543	11395
Mother BMI status by stunting status			
Underweight	488 7.2%	483 10.7%	971
Normal	4805 70.5%	3323 73.4%	8128
Overweight	1525 22.4%	719 15.9%	2244
Total	6818	4525	11343
Covariates	**Non-Stunted** (n = 6,858)	**Stunted** (n = 4,549)	**Total** (n = 11,407)
Wealth index by stunting status			
Poorest	1455 21.2%	1302 28.6%	2757
Poorer	1586 23.1%	1169 25.7%	2755
Middle	1592 23.2%	1013 22.3%	2605
Richer	1208 17.6%	697 15.3%	1905
Richest	1017 14.8%	368 8.1%	1385
Total	6858	4549	11407

Low birthweight by stunting status			
Normal	4495 94.4%	2510 87.5%	7005
Low birthweight	267 5.6%	360 12.5%	627
Total	4762	2870	7632
Child Dietary Diversity Adequacy by Stunting Status			
Inadequate	3720 86.6%	2280 85.5%	6000
Adequate	575 13.4%	387 14.5%	962
Total	4295	2667	6962
Birth order of child			
First child	1392 20.3%	893 19.6%	2285
Second child	1231 17.9%	797 17.5%	2028
Third or more child	4235 61.8%	2859 62.8%	7094
Total	6858	4549	11407

Table 5A.3 Descriptive characteristics of maternal anthropometry in the MDHS stratified by sex of child and stunting status in Aim 1

Madagascar DHS 2008-2009 **Maternal and Child Characteristics Stratified by Sex of Child & Stunting Status**							
Mother short stature (<145cm) by sex of child and stunting status							
Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=1,184)	**Stunted** (n=1,261)	**Total** (n=2,445)		**Non-Stunted** (n=1,317)	**Stunted** (n=1,099)	**Total** (n=2,416)
Normal stature	1124 95.7%	1137 90.5%	2261	Normal stature	1248 95.2%	1004 91.8%	2252
Short stature	51 4.3%	120 9.5%	171	Short stature	63 4.8%	90 8.2%	153
Total	1175	1257	2432	Total	1311	1094	2405

Mother BMI status by sex of child and stunting status							
Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=1,184)	**Stunted** (n=1,261)	**Total** (n=2,445)		**Non-Stunted** (n=1,317)	**Stunted** (n=1,099)	**Total** (n=2,416)
Under-weight	270 23.0%	364 29.0%	634	Under-weight	297 22.7%	330 30.2%	627

Normal	840 71.6%	847 67.4%	1687	Normal	932 71.2%	717 65.6%	1649
Over-weight	64 5.5%	45 358.0%	109	Over-weight	80 6.1%	46 4.2%	126
Total	1174	1256	2430	Total	1309	1093	2402

Wealth index by sex of child and stunting status

Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=1,184)	**Stunted** (n=1,261)	**Total** (n=2,445)		**Non-Stunted** (n=1,317)	**Stunted** (n=1,099)	**Total** (n=2,416)
Poorest	355 30.0%	367 29.1%	722	Poorest	382 29.0%	288 26.2%	670
Poorer	234 19.8%	270 21.4%	504	Poorer	269 20.4%	255 23.2%	524
Middle	202 17.1%	231 18.3%	433	Middle	207 15.7%	214 19.5%	421
Richer	176 14.9%	230 18.2%	406	Richer	206 15.6%	198 18.0%	404
Richest	217 18.3%	163 12.9%	380	Richest	253 19.2%	144 13.1%	397
Total	1184	1261	2445	Total	1317	1099	2416

Low birthweight by sex of child and stunting status

Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=1,184)	**Stunted** (n=1,261)	**Total** (n=2,445)		**Non-Stunted** (n=1,317)	**Stunted** (n=1,099)	**Total** (n=2,416)
Normal	436 92.57%	430 89.21%	866	Normal	511 88.87%	352 83.61%	863
Low birth-weight	35 7.43%	52 10.79%	87	Low birth-weight	64 11.13%	69 16.39%	133
Total	471	482	953	Total	575	421	996

Child dietary diversity adequacy by sex of child and stunting status

Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=1,184)	**Stunted** (n=1,261)	**Total** (n=2,445)		**Non-Stunted** (n=1,317)	**Stunted** (n=1,099)	**Total** (n=2,416)
Inadequate	823 84.7%	854 84.2%	1677	Inadequate	908 84.8%	729 83.7%	1637
Adequate	149 15.3%	160 15.8%	309	Adequate	163 15.2%	142 16.3%	305
Total	972	1014	1986	Total	1071	871	1942

Birth order of child and stunting status

Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=1,184)	**Stunted** (n=1,261)	**Total** (n=2,445)		**Non-Stunted** (n=1,317)	**Stunted** (n=1,099)	**Total** (n=2,416)
First child	292 24.7%	261 20.7%	553	First child	312 23.7%	240 21.8%	552
Second child	221 18.7%	262 20.8%	483	Second child	286 21.7%	168 15.3%	454
Third or more child	671 56.7%	738 58.5%	1409	Third or more child	719 54.6%	691 62.9%	1410
Total	1184	1261	2445	Total	1317	1099	2416

Table 5A.4 Descriptive characteristics of maternal anthropometry in the ZDHS stratified by sex of child and stunting status in Aim 1

Zambia DHS 2013-2014 Maternal and Child Characteristics Stratified by Child Sex & Stunting Status							
Mother short stature (<145cm) by sex of child and stunting status							
Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=3,305)	**Stunted** (n=2,416)	**Total** (n=5,721)		**Non-Stunted** (n=3,553)	**Stunted** (n=2,133)	**Total** (n=5,686)
Normal stature	3272 99.1%	2355 97.5%	5627	Normal stature	3503 98.7%	2052 96.4%	5555
Short stature	30 0.9%	60 2.5%	90	Short stature	47 1.3%	76 3.6%	123
Total	3302	2415	5717	Total	3550	2128	5678

Mother BMI status by sex of child and stunting status							
Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=3,305)	**Stunted** (n=2,416)	**Total** (n=5,721)		**Non-Stunted** (n=3,553)	**Stunted** (n=2,133)	**Total** (n=5,686)
Underweight	246 7.5%	252 10.5%	498	Underweight	242 6.9%	231 10.9%	473
Normal	2321 70.6%	1753 72.9%	4074	Normal	2484 70.4%	1570 74.1%	4054
Overweight	723 22.0%	401 16.7%	1124	Overweight	802 22.7%	318 15.0%	1120
Total	3290	2406	5696	Total	3528	2119	5647

Wealth index by sex of child and stunting status	
Sex of child=Male	Sex of child=Female

	Non-Stunted (n=3,305)	**Stunted** (n=2,416)	**Total** (n=5,721)		**Non-Stunted** (n=3,553)	**Stunted** (n=2,133)	**Total** (n=5,686)
Poorest	705	694	1399	Poorest	750	608	1358
	21.3%	28.7%			21.1%	28.5%	
Poorer	726	605	1331	Poorer	860	564	1424
	22.0%	25.0%			24.2%	26.4%	
Middle	770	551	1321	Middle	822	462	1284
	23.3%	22.8%			23.1%	21.7%	
Richer	584	370	954	Richer	624	327	951
	17.7%	15.3%			17.6%	15.3%	
Richest	520	196	716	Richest	497	172	669
	15.7%	8.1%			14.0%	8.1%	
Total	3305	2416	5721	Total	3553	2133	5686

Low birthweight by sex of child and stunting status							
Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=3,305)	**Stunted** (n=2,416)	**Total** (n=5,721)		**Non-Stunted** (n=3,553)	**Stunted** (n=2,133)	**Total** (n=5,686)
Normal	2206	1385	3591	Normal	2289	1125	3414
	94.8%	89.5%			94.0%	85.0%	
Low birthweight	122	162	284	Low birthweight	145	198	343
	5.2%	10.5%			6.0%	15.0%	
Total	2328	1547	3875	Total	2434	1323	3757

Child dietary diversity adequacy by sex of child and stunting status							
Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=3,305)	**Stunted** (n=2,416)	**Total** (n=5,721)		**Non-Stunted** (n=3,553)	**Stunted** (n=2,133)	**Total** (n=5,686)
Inadequate	1802	1238	3040	Inadequate	1918	1042	2960
	86.8%	84.8%			86.5%	86.3%	
Adequate	275	222	497	Adequate	300	165	465
	13.2%	15.2%			13.5%	13.7%	
Total	2077	1460	3537	Total	2218	1207	3425

Birth order of child and stunting status							
Sex of child=Male				Sex of child=Female			
	Non-Stunted (n=3,305)	**Stunted** (n=2,416)	**Total** (n=5,721)		**Non-Stunted** (n=3,553)	**Stunted** (n=2,133)	**Total** (n=5,686)
First child	672	481	1153	First child	720	412	1132
	20.3%	19.9%			20.3%	19.3%	
Second child	586	432	1018	Second child	645	365	1010
	17.7%	17.9%			18.2%	17.1%	
	2047	1503	3550		2188	1356	3544

Third or more child	61.9%	62.2%		Third or later child	61.6%	63.6%	
Total	3305	2416	5721	Total	3553	2133	5686

Table 5A.5 Madagascar DHS Tetrachoric Correlation Tables in Aim 1

	Stunting	Sex of child	Short mother	Mother BMI	Wealth quintile	Low birthweight	Adeq dietary div
Stunting	-	-0.096	0.211	-0.127	-0.034	0.128	0.020
Sex of child	-0.096	-	-0.032	0.012	0.023	0.139	0.004
Short mother	0.211	-0.032	-	0.010	-0.033	0.032	-0.015
Mother BMI status	-0.127	0.012	0.010	-	0.208	-0.036	0.151
Wealth quintile	-0.034	0.023	-0.033	0.208	-	-0.037	0.419
Low birthweight	0.128	0.139	0.032	-0.036	-0.037	-	0.003
Adequate dietary diversity	0.020	0.004	-0.015	0.151	0.419	0.003	-

Table 5A.6 Madagascar DHS Pearson Correlation Tables in Aim 1

	HAZ score	Sex of child	Mother height	Mother BMI	Child age	Wealth score	Birthweight	Dietary diversity	Birth order
HAZ score	-	0.058	0.143	0.075	-0.217	0.045	0.086	-0.059	-0.115
Sex of child	0.058	-	-0.005	0.010	-0.014	0.003	0.086	-0.059	-0.115
Mother height	0.143	-0.005	-	-0.017	0.043	0.086	0.092	0.009	-0.029
Mother BMI	0.075	0.010	-0.017	-	0.031	0.274	0.075	0.040	-0.046

Child age	-0.217	-0.014	0.043	0.031	-	0.022	0.019	0.192	0.529
Wealth score	0.045	0.003	0.086	0.274	0.022	-	0.059	0.246	-0.133
Birthweight	0.086	0.086	0.092	0.075	0.019	0.059	-	0.000	-0.008
Dietary diversity	-0.059	-0.059	0.009	0.040	0.192	0.246	0.000	-	-0.116
Birth order	-0.115	-0.115	-0.029	-0.046	0.529	-0.133	-0.008	-0.116	-

Table 5A.7 Zambia DHS Tetrachoric Correlation Tables in Aim 1

	Stunting	**Sex of child**	**Short mother**	**Mother BMI**	**Wealth quintile**	**Low birthweight**	**Adeq dietary div**
Stunting	-	-0.077	0.246	-0.143	-0.165	0.269	0.031
Sex of child	-0.077	-	0.081	0.007	-0.009	0.074	-0.014
Short mother	0.246	0.081	-	-0.083	-0.190	0.067	0.019
Mother BMI status	-0.143	0.007	-0.083	-	0.337	-0.091	0.101
Wealth quintile	-0.165	-0.009	-0.190	0.337	-	-0.021	0.219
Low birthweight	0.269	0.074	0.067	-0.091	-0.021	-	-0.003
Adequate dietary diversity	0.031	-0.014	0.019	0.101	0.219	-0.003	-

Table 5A.8 Zambia DHS Pearson Correlation Tables in Aim 1

	HAZ score	**Sex of child**	**Mother height**	**Mother BMI**	**Wealth score**	**Birthweight**	**Dietary diversity**	**Birth order**
HAZ score	-	0.055	0.039	0.122	0.145	0.131	-0.087	-0.065
Sex of child	0.055	-	0.013	0.002	0.001	-0.081	-0.004	-0.004

Mother height	0.039	0.013	-	0.073	0.006	0.016	0.024	-0.009
Mother BMI	0.122	0.002	0.073	-	0.361	0.098	0.036	-0.046
Wealth score	0.145	0.001	0.006	0.361	-	-0.026	0.116	-0.124
Birthweight	0.131	-0.081	0.016	0.098	-0.026	-	0.028	-0.010
Dietary diversity	-0.087	-0.004	0.024	0.036	0.116	0.028	-	-0.086
Birth order	-0.065	-0.004	-0.009	-0.046	-0.124	-0.010	-0.086	-

Table 5A.9 Bivariate Odds Ratios for Maternal and Child characteristics in Relation to Child Stunting in Madagascar in Aim 1

	Stunting outcome n = 4,861		Stunting outcome n = 4,861		Stunting outcome n = 4,861	
	Logistic		Logistic - Males		Logistic - Females	
Exposure Variables	OR	95% CI	OR	95% CI	OR	95% CI
Child gender						
Female (ref)						
Male	1.28	[1.14, 1.43]	-	-	-	-
Mother's stature						
Normal (≥ 145cm) (ref)						
Short (< 145cm)	2.04	[1.61, 2.58]	2.33	[1.66, 3.26]	1.78	[1.27, 2.48]
Mother's BMI status						
Normal (18.5 ≤ BMI < 25) (ref)						
Overweight (BMI ≥ 25)	0.72	[0.55, 0.94]	0.70	[0.47, 1.03]	0.75	[0.51, 1.09]
Underweight (BMI < 18.5)	1.39	[1.22, 1.58]	1.34	[1.11, 1.61]	1.44	[1.20, 1,74]
Covariates						
Household wealth quintile						
Richest (ref)						
Richer	1.72	[1.41, 2.09]	1.74	[1.31, 2.31]	1.69	[1.27, 2.24]
Middle	1.67	[1.37, 2.03]	1.52	[1.15. 2.01]	1.82	[1.37, 2.40]
Poorer	1.60	[1.32, 1.93]	1.54	[1.18, 2.01]	1.67	[1.28, 2.18]
Poorest	1.36	[1.14, 1.63]	1.38	[1.07, 1.77]	1.33	[1.03, 1.71]
Birthweight						
Normal (ref)						
Low	1.48	[1.12, 1.96]	1.51	[0.96, 2.36]	1.57	[1.09, 2.26]
Child Dietary Diversity						
Adequate (score of 4+), (ref)						
Inadequate (scores less than 4)	0.95	[0.80, 1.12]	0.97	[0.76, 1.23]	0.92	[0.72, 1.18]
Birth order						
First child (ref)						
Second child	1.02	[0.86, 1.22]	1.33	[1.04, 1.69]	0.76	[0.59, 0.99]
Third or more	1.24	[1.08, 1.43]	1.23	[1.01, 1.50]	1.25	[1.03, 1.52]
Mother's height (cm)	0.95	[0.94, 0.96]	0.95	[0.94, 0.96]	0.95	[0.93, 0.96]
Mother's BMI	0.94	[0.93, 0.96]	0.94	[0.91, 0.97]	0.95	[0.92, 0.98]
Birthweight (grams)	0.73	[0.63, 0.84]	0.61	[0.50, 0.76]	0.80	[0.66, 0.98]
Child dietary diversity score	1.08	[1.04, 1.13]	1.05	[0.99, 1.12]	1.11	[1.05, 1.18]
Birth order	1.48	[1.34, 1.64]	1.44	[1.24, 1.67]	1.53	[1.32, 1.76]

Table 5A.10 Bivariate Linear Coefficients for Maternal and Child characteristics in Relation to Child Stunting in Madagascar in Aim 1

	Height-for-age z-score n = 4,861		Height-for-age z-score n = 4,861		Height-for-age z-score n = 4,861	
	Linear		Linear - Males		Linear - Females	
Exposure Variables	beta	95% CI	beta	95% CI	beta	95% CI
Child gender						
Female (ref)						
Male	-0.219	(-0.325, -0.112)	-	-	-	-
Mother's stature						
Normal (≥ 145cm) (ref)						
Short (< 145cm)	-0.651	(-0.864, -0.438)	-0.700	(-0.999, -0.401)	-0.585	(-0.888, -0.282)
Mother's BMI status						
Normal (18.5 ≤ BMI < 25) (ref)						
Overweight (BMI ≥ 25)	0.204	(-0.046, 0.454)	0.436	(0.063, 0.809)	-0.019	(-0.353, 0.316)
Underweight (BMI < 18.5)	-0.330	(-0.452, -0.207)	-0.271	(-0.447, -0.095)	-0.391	(-0.561, -0.221)
Covariates						
Household wealth quintile						
Richest (ref)						
Richer	-0.473	(-0.659, -0.287)	-0.449	(-0.719, -0.180)	-0.491	(-0.747, -0.235)
Middle	-0.378	(-0.561, -0.194)	-0.277	(-0.543, -0.011)	-0.472	(-0.725, -0.218)
Poorer	-0.324	(-0.500, -0.148)	-0.303	(-0.559, -0.046)	-0.344	(-0.585, -0.103)
Poorest	-0.213	(-0.379, -0.047)	-0.211	(-0.450, 0.029)	-0.199	(-0.428, 0.031)
Birthweight						
Normal (ref)						
Low	-0.391	(-0.654, -0.129)	-0.205	(-0.629, 0.219)	-0.577	(-0.908, -0.246)
Child Dietary Diversity						
Adequate (score of 4+), (ref)						
Inadequate (scores less than 4)	0.074	(-0.095, 0.253)	0.034	(-0.209, 0.277)	-0.109	(-0.167, -0.050)
Mother's height (cm)	0.046	(0.037, 0.055)	0.048	(0.036, 0.061)	0.044	(0.031, 0.056)
Mother's BMI	0.051	(0.032, 0.070)	0.057	(0.029, 0.085)	0.044	(0.018, 0.070)
Birthweight (grams)	0.256	(0.124, 0.388)	0.308	(0.112, 0.504)	0.252	(0.073, 0.430)
Child dietary diversity score	-0.080	(-0.122, -0.038)	-0.051	(-0.112, 0.010)	-0.109	(-0.167, -0.051)
Birth order	-0.389	(-0.483, -0.295)	-0.322	(-0.459, -0.185)	-0.451	(-0.579, -0.322)

Table 5A.11 Bivariate Odds Ratios for Maternal and Child characteristics in Relation to Child Stunting in Zambia in Aim 1

	Stunting outcome n = 11,407		Stunting outcome n = 11,407		Stunting outcome n = 11,407	
	Logistic		Logistic - Males		Logistic - Females	
Exposure Variables	OR	95% CI	OR	95% CI	OR	95% CI
Child gender						
Female (ref)						
Male	1.22	[1.13. 1.31]	-	-	-	-
Mother's stature						
Normal (≥ 145cm) (ref)						
Short (< 145cm)	2.72	[2.05, 3.60]	2.78	[1.79, 4.32]	2.76	[1.91, 3.99]
Mother's BMI status						
Normal (18.5 ≤ BMI < 25) (ref)						
Overweight (BMI ≥ 25)	0.68	[0.62, 0.75]	0.73	[0.64, 0.84]	0.63	[0.54, 0.73]
Underweight (BMI < 18.5)	1.43	[1.25. 1.64]	1.36	[1.13, 1.63]	1.51	[1.25, 1.83]
Covariates						
Child age category						
0-23 months (ref)						
24-60 months	1.37	[1.27, 1.48]	1.17	[1.05, 1.30]	1.62	[1.45, 1.82]
Household in wealthy quintiles						
Yes (ref)						
No	1.57	[1.44, 1.71]	1.64	[1.46, 1.85]	1.51	[1.34, 1.71]
Household wealth quintile						
Richest (ref)						
Richer	1.60	[1.37, 1.86]	1.68	[1.36, 2.07]	1.51	[1.22, 1.88]
Middle	1.76	[1.52, 2.03]	1.90	[1.56, 2.31]	1.62	[1.32, 2.00]
Poorer	2.04	[1.77, 2.35]	2.21	[1.82, 2.69]	1.89	[1.55, 2.32]
Poorest	2.47	[2.15, 2.85]	2.61	[2.15, 3.17]	2.34	[1.91, 2.87]
Mother secondary education						
Yes (ref)						
No	1.44	[1.33, 1.56]	1.35	[1.20, 1.51]	1.55	[1.37, 1.74]
Mother's education level						
Higher (ref)						
Secondary	2.75	[2.10, 3.61]	3.00	[2.07, 4.34]	2.53	[1.69, 3.79]
Primary	3.58	[2.74, 4.68]	3.62	[2.52, 5.20]	3.58	[2.41, 5.32]
No education	3.80	[2.86, 5.05]	3.81	[2.58, 5.61]	3.83	[2.52, 5.83]
Urban or rural location						
Urban (ref)						
Rural	1.30	[1.20, 1.41]	1.39	[1.25, 1.55]	1.21	[1.09, 1.36]
Birthweight						
Normal (ref)						
Low	2.41	[2.05, 2.85]	2.12	[1.66, 2.70]	2.78	[2.22, 3.48]
Child Dietary Diversity						
Adequate (score of 4+), (ref)						
Inadequate (scores less than 4)	0.91	[0.79, 1.05]	0.85	[0.70, 1.03]	0.99	[0.81, 1.21]
Birth order						
First child (ref)						
Second child	1.01	[0.89, 1.14]	1.03	[0.87, 1.22]	0.99	[0.83, 1.18]
Third or more	1.05	[0.96, 1.16]	1.03	[0.90, 1.17]	1.08	[0.94, 1.24]

Household size						
5 members or less (ref)						
More than 5 members	0.90	[0.84, 0.98]	0.80	[0.71, 0.89]	1.03	[0.92, 1.15]
Children under 5 in household						
3 or less children (ref)						
More than 3 children	1.23	[1.03, 1.48]	1.33	[1.04, 1.72]	1.11	[0.84, 1.45]
Mother's height (cm)	0.99	[0.98, 0.99]	1.00	[0.99, 1.00]	0.97	[0.97, 0.98]
Mother's height-for-age z-score	0.68	[0.65, 0.71]	0.68	[0.64, 0.72]	0.68	[0.64, 0.72]
Mother's BMI	0.95	[0.94, 0.96]	0.95	[0.94, 0.96]	0.95	[0.93, 0.96]
Mother's age	1.00	[0.99, 1.00]	1.00	[1.00, 1.00]	1.00	[1.00, 1.00]
Child age	1.01	[1.01, 1.01]	1.00	[1.00, 1.01]	1.02	[1.01, 1.02]
Years of mother's education	0.95	[0.94, 0.96]	0.95	[0.94, 0.97]	0.94	[0.93, 0.96]
Birthweight (g)	0.62	[0.57, 0.67]	0.61	[0.55, 0.69]	0.61	[0.54, 0.68]
Child Dietary Diversity Score	1.09	[1.06, 1.12]	1.10	[1.06, 1.15]	1.08	[1.03, 1.13]
Number of household members	0.98	[0.97, 0.99]	0.97	[0.95, 0.99]	0.99	[0.97, 1.01]
Number of children under 5 in household	1.08	[1.04, 1.13]	1.08	[1.02, 1.15]	1.08	[1.02, 1.15]
Birth order	1.15	[1.07, 1.23]	1.06	[0.95, 1.17]	1.25	[1.13, 1.38]

Table 5A.12 Bivariate Linear Coefficients for Maternal and Child characteristics on Child Stunting in Zambia in Aim 1

	Height-for-age z-score n = 11,407		Height-for-age z-score n = 11,407		Height-for-age z-score n = 11,407	
	Linear Regression		Linear - Male		Linear - Female	
Exposure Variables	beta	95% CI	beta	95% CI	beta	95% CI
Child gender						
Female (ref)						
Male	-0.177	(-0.236, -0.118)	-	-	-	-
Mother's stature						
Normal (≥ 145cm) (ref)						
Short (< 145cm)	-0.692	(-0.910, -0.474)	-0.790	(-1.128, -0.453)	-0.645	(-0.929, -0.362)
Mother's BMI status						
Normal (18.5 ≤ BMI < 25) (ref)						
Overweight (BMI ≥ 25)	0.348	(-0.273, 0.423)	0.320	(0.214, 0.427)	0.376	(0.272, 0.480)
Underweight (BMI < 18.5)	-0.347	(-0.453, -0.241)	-0.279	(-0.429, -0.128)	-0.415	(-0.565, -0.265)
Covariates						
Household wealth quintile						
Richest (ref)						
Richer	-0.415	(-0.526, -0.305)	-0.528	(-0.684, -0.373)	-0.303	(-0.459, -0.147)
Middle	-0.538	(-0.641, -0.434)	-0.622	(-0.768, -0.477)	-0.451	(-0.598, -0.303)
Poorer	-0.588	(-0.691, -0.485)	-0.655	(-0.800, -0.509)	-0.527	(-0.672, -0.382)
Poorest	-0.767	(-0.870, -0.664)	-0.872	(-1.016, -0.727)	-0.659	(-0.805, -0.513)
Birthweight						
Normal (ref)						
Low	-0.608	(-0.741, -0.476)	-0.564	(-0.761, -0.367)	-0.666	(-0.845, -0.487)
Child Dietary Diversity						
Adequate (score of 4+), (ref)						
Inadequate (scores less than 4)	0.135	(0.019, 0.250)	0.143	(-0.021, 0.307)	0.121	(-0.041, 0.284)
Mother's height (cm)	0.002	(0.001, 0.003)	0.002	(0.000, 0.003)	0.002	(0.001, 0.004)
Mother's BMI	0.052	(0.044, 0.060)	0.054	(0.042, 0.065)	0.050	(0.039, 0.061)
Birthweight (g)	0.355	(0.295, 0.416)	0.386	(0.301, 0.470)	0.352	(0.265, 0.438)
Child Dietary Diversity Score	-0.094	(-0.119, -0.068)	-0.092	(-0.128, -0.057)	-0.093	(-0.128, -0.058)
Birth order	-0.198	(-0.254, -0.142)	-0.113	(-0.194, -0.032)	-0.280	(-0.357, -0.203)

Figure 6A.1 Household water and sanitation map in Madagascar 2008-2009

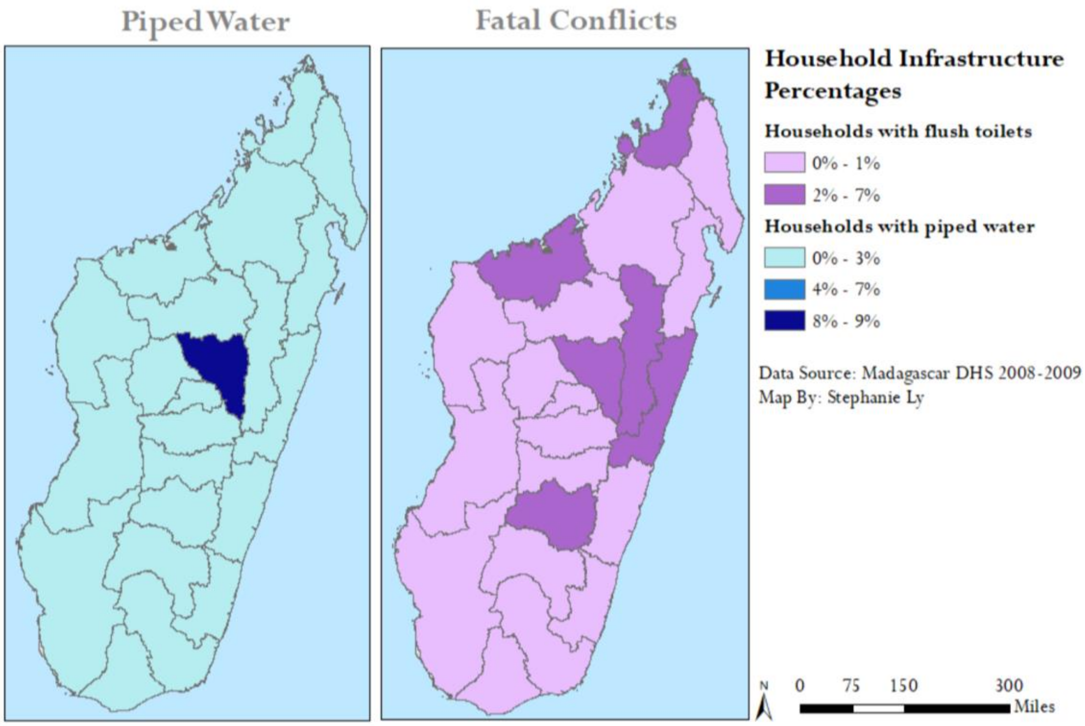


Figure 6A.2 Household water and sanitation map in Zambia 2013-2014

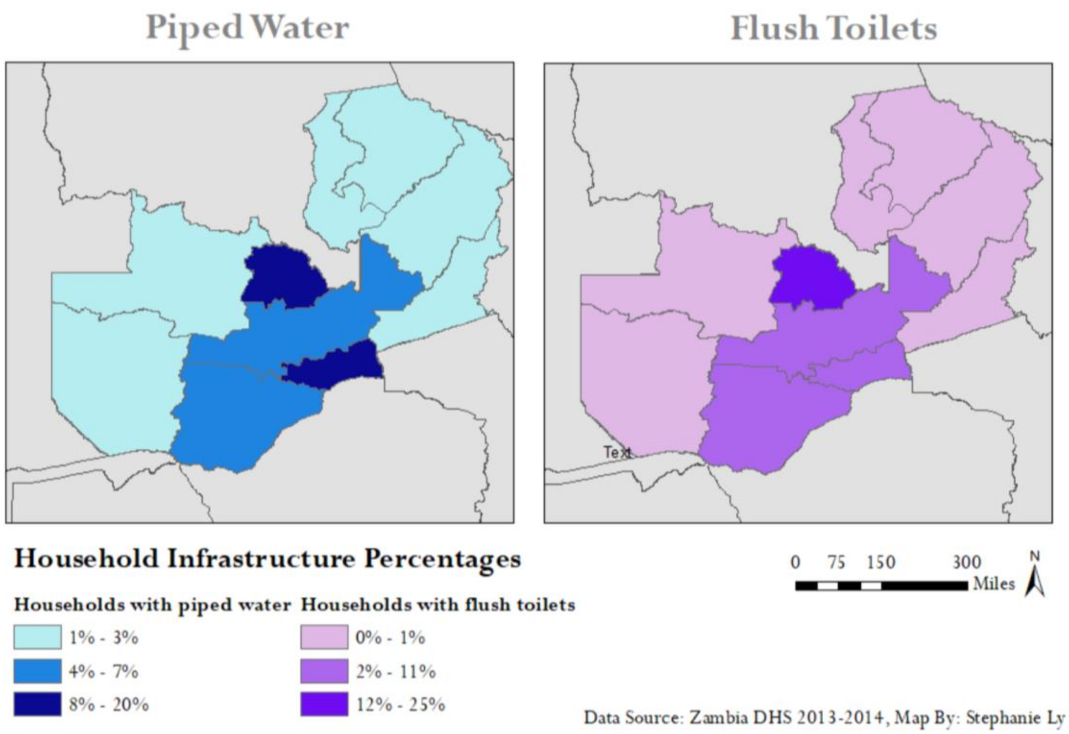


Table 6A.1 Descriptive Characteristics of MDHS Study Sample of Children 0-59 months in Aim 2

Madagascar DHS 2008-2009 Sanitation Categorical Variables by Binary Stunting Outcome			
Predictors	**Non-stunted** (n=2,501)	**Stunted** (n=2,360)	**Total** (n=4,861)
Flush toilet to sewer or septic tank by stunting status			
No	2407	2319	4726
	50.90%	49.10%	
Yes	64	32	96
	66.70%	33.30%	
Total	2471	2351	4822
Type of toilet facility (ordinal - poor, intmd, high) by stunting status			
Poor	1443	1284	2727
	52.90%	47.10%	
Intermediate	932	988	1920
	48.50%	51.50%	
High	96	79	175
	54.90%	45.10%	
Total	2471	2351	4822
Piped into home by stunting status			
No	2408	2321	4729
	50.90%	49.10%	
Yes	49	16	65
	75.40%	24.60%	
Total	2457	2337	4794
Source of drinking water (ordinal - poor, intmd, high) by stunting status			
Poor	566	519	1085
	52.20%	47.80%	
Intermediate	1777	1768	3545
	50.10%	49.90%	
High	114	50	164
	69.50%	30.50%	
Total	2457	2337	4794
Household has finished flooring (cement, tiles, carpet) by stunting status			
No	1859	1916	3775
	49.20%	50.80%	
Yes	612	433	1045
	58.60%	41.40%	
Total	2471	2349	4820
Owns any cattle, pigs, or chickens by stunting status			
No	781	725	1506
	51.90%	48.10%	

Yes	1720 51.30%	1635 48.70%	3355
Total	2501	2360	4861
Owns cattle by stunting status			
No	1642 50.50%	1610 49.50%	3252
Yes	859 53.40%	749 46.60%	1608
Total	2501	2359	4860
Owns chickens by stunting status			
No	1032 51.80%	961 48.20%	1993
Yes	1464 51.30%	1390 48.70%	2854
Total	2496	2351	4847
Owns pigs by stunting status			
No	2142 52.80%	1912 47.20%	4054
Yes	357 44.30%	448 55.70%	805
Total	2499	2360	4859
Share toilet by stunting status			
Not at all	371 52.20%	340 47.80%	711
Less than once a week	671 47.60%	739 52.40%	1410
Total	1042	1079	2121
Anything done to water to make safe to drink by stunting status			
No	930 56.20%	725 43.80%	1655
Yes	870 53.30%	761 46.70%	1631
Total	1800	1486	3286
Had diarrhea in last 2 weeks by stunting status			
No	2280 51.30%	2163 48.70%	4443
Yes	216 52.70%	194 47.30%	410
Total	2496	2357	4853
Wealth index by stunting status			
Poorest	737 52.90%	655 47.10%	1392
Poorer	503 48.90%	525 51.10%	1028

Middle	409 47.90%	445 52.10%	854
Richer	382 47.20%	428 52.80%	810
Richest	470 60.50%	307 39.50%	777
Total	2501	2360	4861
Wealthy or wealthiest quintile households by stunting status			
No	1649 50.40%	1625 49.60%	3274
Yes	852 53.70%	735 46.30%	1587
Total	2501	2360	4861
Highest educational level by stunting status			
No education	725 53.10%	641 46.90%	1366
Primary	1195 48.20%	1284 51.80%	2479
Secondary	537 56.30%	416 43.70%	953
Higher	44 69.80%	19 30.20%	63
Total	2501	2360	4861
Mother completed secondary education by stunting status			
No	1920 49.90%	1925 50.10%	3845
Yes	581 57.20%	435 42.80%	1016
Total	2501	2360	4861
Urban or rural location by stunting status			
Urban	509 57.80%	371 42.20%	880
Rural	1992 50.00%	1989 50.00%	3981
Total	2501	2360	4861
Child Dietary Diversity Adequacy by stunting status			
Inadequate	1731 52.20%	1583 47.80%	3314
Adequate	312 50.80%	302 49.20%	614
Total	2043	1885	3928

Table 6A.2 Descriptive Characteristics of ZDHS Study Sample of Children 0-59 months in Aim 2

Zambia DHS 2013-2014 Sanitation Categorical Variables by Binary Stunting Outcome			
Predictors	**Non-stunted** (n=6,858)	**Stunted** (n=4,549)	**Total** (n=11,407)
Flush toilet to sewer or septic tank by stunting status			
No	6032 58.80%	4228 41.20%	10260
Yes	675 74.60%	230 25.40%	905
Total	6707	4458	11165
Type of toilet facility (ordinal - poor, intmd, high) by stunting status			
Poor	1111 57.40%	824 42.60%	1935
Intermediate	4899 59.10%	3389 40.90%	8288
High	697 74.00%	245 26.00%	942
Total	6707	4458	11165
Piped into home by stunting status			
No	6257 59.10%	4327 40.90%	10584
Yes	422 78.90%	113 21.10%	535
Total	6679	4440	11119
Source of drinking water (ordinal - poor, intmd, high) by stunting status			
Poor	792 54.20%	669 45.80%	1461
Intermediate	4910 59.00%	3414 41.00%	8324
High	977 73.20%	357 26.80%	1334
Total	6679	4440	11119
Household has finished flooring (cement, tiles, carpet) by stunting status			
No	4210 56.90%	3187 43.10%	7397
Yes	2502 66.20%	1277 33.80%	3779
Total	6712	4464	11176
Owns any cattle, pigs, or chickens by stunting status			
No	3246 61.00%	2078 39.00%	5324
Yes	3612	2470	6082

	59.40%	40.60%	
Total	6858	4548	11406
Owns cattle by stunting status			
No	5745	3857	9602
	59.80%	40.20%	
Yes	1113	691	1804
	61.70%	38.30%	
Total	6858	4548	11406
Owns chickens by stunting status			
No	3525	2239	5764
	61.20%	38.80%	
Yes	3323	2306	5629
	59.00%	41.00%	
Total	6848	4545	11393
Owns pigs by stunting status			
No	6112	4046	10158
	60.20%	39.80%	
Yes	745	502	1247
	59.70%	40.30%	
Total	6857	4548	11405
Share toilet by stunting status			
No	3675	2344	6019
	61.10%	38.90%	
Yes	1940	1308	3248
	59.70%	40.30%	
Total	5615	3652	9267
Anything done to water to make safe to drink by stunting status			
No	4794	3292	8086
	59.30%	40.70%	
Yes	2059	1255	3314
	62.10%	37.90%	
Total	6853	4547	11400
Had diarrhea in last 2 weeks by stunting status			
No	5768	3711	9479
	60.90%	39.10%	
Yes	1081	830	1911
	56.60%	43.40%	
Total	6849	4541	11390
Wealth index by stunting status			
Poorest	1455	1302	2757
	52.80%	47.20%	
Poorer	1586	1169	2755
	57.60%	42.40%	

Middle	1592 61.10%	1013 38.90%	2605
Richer	1208 63.40%	697 36.60%	1905
Richest	1017 73.40%	368 26.60%	1385
Total	6858	4549	11407
Wealthy or wealthiest quintile households by stunting status			
No	4633 57.10%	3484 42.90%	8117
Yes	2225 67.60%	1065 32.40%	3290
Total	6858	4549	11407
Highest educational level by stunting status			
No education	724 56.20%	565 43.80%	1289
Primary	3688 57.60%	2716 42.40%	6404
Secondary	2117 63.90%	1197 36.10%	3314
Higher	326 83.00%	67 17.00%	393
Total	6855	4545	11400
Mother completed secondary education by stunting status			
No	4412 57.40%	3281 42.60%	7693
Yes	2443 65.90%	1264 34.10%	3707
Total	6855	4545	11400
Urban or rural location by stunting status			
Urban	2647 64.10%	1482 35.90%	4129
Rural	4211 57.90%	3067 42.10%	7278
Total	6858	4549	11407
Child Dietary Diversity Adequacy by stunting status			
Inadequate	3720 62.00%	2280 38.00%	6000
Adequate	575 59.80%	387 40.20%	962
Total	4295	2667	6962

Table 6A.3 Madagascar DHS Tetrachoric Correlation Table in Aim 2

	Stunting	Flush toilet	Piped water	Finished Floor	Any sanitation animals	Share toilet	Treat water	Diarrhea	Wealthy household	Mother's secondary education	Urban
Stunting	-	-0.16	-0.25	-0.14	0.01	0.07	0.05	-0.02	-0.05	-0.10	0.11
Flush toilet	-0.16	-	0.86	0.68	-0.42	-0.26	0.13	0.01	-	0.67	-0.71
Piped water	-0.25	0.86	-	0.67	-0.44	-0.36	0.12	0.03	-	0.73	-0.76
Finished Floor	-0.14	0.68	0.67	-	-0.32	0.08	0.15	0.07	0.91	0.70	-0.72
Any sanitation animals	0.01	-0.42	-0.44	-0.32	-	-0.25	0.00	0.02	-0.33	-0.26	0.57
Share toilet	0.07	-0.26	-0.36	0.08	-0.25	-	-0.04	0.10	0.11	0.03	-0.24
Treat water	0.05	0.13	0.12	0.15	0.00	-0.04	-	-0.01	0.18	0.26	-0.15
Diarrhea	-0.02	0.01	0.03	0.07	0.02	0.10	-0.01	-	0.04	0.02	-0.09
Wealthy household	-0.05	-	-	0.91	-0.33	0.11	0.18	0.04	-	0.75	-0.82
Mother's secondary education	-0.10	0.67	0.73	0.70	-0.26	0.03	0.26	0.02	0.75	-	-0.63
Urban	0.11	-0.71	-0.76	-0.72	0.57	-0.24	-0.15	-0.09	-0.82	-0.63	-

Table 6A.4 Madagascar DHS Pearson Correlation Table in Aim 2

	Height-for-age z-score	Flush toilet	Piped water	Finished Floor	Number of cattle	Number of chickens	Number of pigs	Child age	Diarrhea	Wealth score	Years of education	Urban
Height-for-age z-score	-	0.03	0.04	0.06	0.02	0.01	-0.01	-0.22	0.00	0.05	0.03	-0.04
Flush toilet	0.03	-	0.48	0.23	-0.03	-0.03	0.00	0.01	0.01	0.37	0.30	-0.24
Piped water	0.04	0.48	-	0.20	-0.03	-0.02	0.05	0.01	0.01	0.37	0.30	-0.24
Finished Floor	0.06	0.23	0.20	-	-0.05	-0.03	0.03	0.03	0.03	0.75	0.50	-0.48
Number of cattle	0.02	-0.03	-0.03	-0.05	-	0.11	0.03	-0.01	0.02	-0.10	-0.11	0.10
Number of chickens	0.01	-0.03	-0.02	-0.03	0.11	-	0.15	0.02	-0.02	-0.05	0.02	0.13
Number of pigs	-0.01	0.00	0.05	0.03	0.03	0.15	-	0.03	0.00	0.04	0.05	0.04
Child age	-0.22	0.01	0.01	0.03	-0.01	0.02	0.03	-	0.00	0.04	0.05	0.04
Diarrhea	0.00	0.01	0.01	0.03	0.02	-0.02	0.00	0.00	-	0.02	0.00	-0.04
Wealth score	0.05	0.37	0.37	0.75	-0.10	-0.05	0.04	0.04	0.02	-	0.68	-0.67
Years of education	0.03	0.30	0.30	0.50	-0.11	0.02	0.05	0.05	0.00	0.68	-	-0.43
Urban	-0.04	-0.24	-0.24	-0.48	0.10	0.13	0.04	0.04	-0.04	-0.67	-0.43	-

Table 6A.5 Zambia DHS Tetrachoric Correlation Table in Aim 2

	Stunting	Flush Toilet	Piped Water	Finished floors	Any sanitation animals	Share toilet	Treat water	Diarrhea	Wealthy household	Mother's secondary education	Urban
Stunting	-	-0.21	-0.25	-0.15	0.02	0.02	-0.04	0.06	-0.17	-0.14	0.10
Flush Toilet	-0.21	-	0.89	0.88	-0.51	-0.22	0.40	0.01	0.95	0.69	-0.78
Piped Water	-0.25	0.89	-	0.83	-0.45	-0.32	0.38	-0.07	0.86	0.64	-0.72
Finished floors	-0.15	0.88	0.83	-	-0.49	0.23	0.40	0.04	0.94	0.63	-0.79
Any sanitation animals	0.02	-0.51	-0.45	-0.49	-	-0.33	-0.19	-0.04	-0.50	-0.27	0.67
Share toilet	0.02	-0.22	-0.32	0.23	-0.33	-	0.02	0.09	0.17	0.05	-0.35
Treat water	-0.04	0.40	0.38	0.40	-0.19	0.02	-	0.02	0.42	0.34	-0.35
Diarrhea	0.06	0.01	-0.07	0.04	-0.04	0.09	0.02	-	0.05	0.01	-0.07
Wealthy household	-0.17	0.95	0.86	0.94	-0.50	0.17	0.42	0.05	-	0.65	-0.82
Mother's secondary education	-0.14	0.69	0.64	0.63	-0.27	0.05	0.34	0.01	0.65	-	-0.53
Urban	0.10	-0.78	-0.72	-0.79	0.67	-0.35	-0.35	-0.07	-0.82	-0.53	-

Table 6A.6 Zambia DHS Pearson Correlation Table in Aim 2

	Height-for-age z-score	Flush toilet	Piped water	Finished Floor	Number of cattle	Number of chickens	Number of pigs	Child age	Diarrhea	Wealth score	Mother's years of education	Urban
Height-for-age z-score	-	0.11	0.12	0.10	0.02	0.00	0.01	-0.14	-0.03	0.15	0.11	-0.08
Flush toilet	0.11	-	0.58	0.41	-0.03	-0.06	-0.02	-0.01	-0.02	0.54	0.33	-0.28
Piped water	0.12	0.58	-	0.31	-0.01	-0.03	-0.03	-0.01	-0.02	0.54	0.33	-0.28
Finished Floor	0.10	0.41	0.31	-	0.00	-0.09	-0.04	0.01	0.02	0.77	0.45	-0.57
Number of cattle	0.02	-0.03	-0.01	0.00	-	0.23	0.20	-0.02	-0.01	0.05	0.01	0.12
Number of chickens	0.00	-0.06	-0.03	-0.09	0.23	-	0.14	0.01	-0.02	-0.03	0.00	0.23
Number of pigs	0.01	-0.03	-0.03	-0.04	0.20	0.14	-	0.01	0.01	-0.02	-0.04	0.11
Child age	-0.14	-0.01	-0.01	0.01	-0.02	0.01	0.01	-	-0.15	0.01	-0.03	-0.01
Diarrhea	-0.03	-0.02	-0.02	0.02	-0.01	-0.02	0.01	-0.15	-	0.01	0.00	-0.04
Wealth score	0.15	0.54	0.54	0.77	0.05	-0.03	-0.02	0.01	0.01	-	0.58	-0.63
Mother's years of education	0.11	0.33	0.33	0.45	0.01	0.00	-0.04	-0.03	0.00	0.58	-	-0.37
Urban	-0.08	-0.28	-0.28	-0.57	0.12	0.23	0.11	-0.01	-0.04	-0.63	-0.37	-

Table 6A.7 Bivariate logistic and linear regression models of child stunting on sanitation factors in Madagascar in Aim 2

	Stunting outcome n = 4,861		Height-for-age z-score n = 4,861	
	Logistic		OLS	
Exposure Variables	OR	95% CI	beta	95% CI
Flush toilet				
Yes (ref)				
No	1.93	[1.26, 2.96]	-0.390	(-0.773, -0.007)
Toilet type - ordinal				
High (ref)				
Intermediate	1.29	[0.94, 1.76]	-0.160	(-0.453, 0.133)
Poor	1.08	[0.80, 1.47]	0.045	(-0.245, 0.334)
Piped water				
Yes (ref)				
No	2.95	[1.67, 5.21]	-0.576	(-1.040, -0.112)
Drinking water source - ordinal				
High (ref)				
Intermediate	2.27	[1.62, 3.18]	-0.523	(-0.820, -0.226)
Poor	2.09	[1.47, 2.98]	-0.409	(-0.720, -0.098)
Finished flooring				
Yes (ref)				
No	1.46	[1.27, 1.67]	-0.269	(-0.399, -0.140)
Floor type - binary				
Improved (ref)				
Unimproved	1.71	[1.47, 1.98]	-0.386	(-0.524, -0.249)
Ownership of cattle				
No (ref)				
Yes	0.89	[0.79, 1.00]	-0.087	(-0.200, 0.027)
Ownership of chickens				
No (ref)				
Yes	1.02	[0.91, 1.14]	-0.039	(-0.147, 0.070)
Ownership of pigs				
No (ref)				
Yes	1.41	[1.21, 1.64]	0.277	(0.133, 0.420)
Own any sanitation animals (chickens, cattle, or pigs)				
No (ref)				
Yes	1.02	[0.91, 1.16]	-0.061	(-0.176, 0.054)
Share toilet with other households				
No (ref)				
Yes	1.20	[1.00, 1.44]	-0.006	(-0.172, 0.159)
Any treatment of water				
Yes (ref)				
No	0.89	[0.78, 1.02]	0.149	(0.014, 0.283)
Treat water by boil				

Yes (ref)				
No	0.91	[0.79, 1.04]	-0.133	(-0.269, 0.003)
Treat water by bleach				
Yes (ref)				
No	1.45	[0.61, 3.46]	0.437	(-0.388, 1.263)
Household has water/tap				
Yes (ref)				
No	1.18	[0.99, 1.41]	0.250	(0.079, 0.421)
Household has soap				
Yes (ref)				
No	1.08	[0.95, 1.24]	-0.003	(-0.131, 0.125)
Covariates				
Child gender				
Female (ref)				
Male	1.28	[1.14, 1.43]	-0.219	(-0.325, -0.112)
Child age	0.85	[0.79, 0.91]	-0.024	(-0.027, -0.021)
Child age category				
0-23 months (ref)				
24-60 months	1.70	[1.51, 1.91]	-0.692	(-0.799, -0.584)
Diarrhea in last 2 weeks				
No (ref)				
Yes	0.95	[0.77, 1.16]	0.011	(-0.181, 0.203)
Wealth score	0.85	[0.79, 0.91]	0.100	(0.037, 0.162)
Household in wealthiest quintiles				
Yes (ref)				
No	1.14	[1.01, 1.29]	-0.049	(-0.163, 0.064)
Household wealth quintile				
Richest (ref)				
Richer	1.72	[1.41, 2.09]	-0.473	(-0.659, -0.287)
Middle	1.67	[1.37, 2.03]	-0.378	(-0.561, -0.194)
Poorer	1.60	[1.32, 1.93]	-0.324	(-0.500, -0.148)
Poorest	1.36	[1.14, 1.63]	-0.213	(-0.379, -0.047)
Mother's years of education	0.97	[0.93, 1.01]	0.028	(-0.000, 0.056)
Mother secondary education				
Yes (ref)				
No	1.33	[1.17, 1.54]	-0.167	(-0.298, -0.036)
Mother's education level				
Higher (ref)				
Secondary	1.79	[1.03, 3.12]	-0.591	(-1.073, -0.108)
Primary	2.49	[1.44, 4.28]	-0.786	(-1.259, -0.312)
No education	2.05	[1.18, 3.54]	-0.604	(-1.082, -0.126)
Child Dietary Diversity				
Adequate (score of 4+), (ref)				
Inadequate (scores less than 4)	0.95	[0.80, 1.12]	0.074	(-0.095, 0.023)
Urban or rural location				

Urban (ref)				
Rural	1.37	[1.18, 1.59]	0.193	(0.054, 0.331)

Table 6A.8 Bivariate and linear logistic regression models of child stunting on sanitation factors in Zambia in Aim 2

	Stunting outcome n = 11,407		**Height-for-age z-score n = 11,407**	
	Logistic		**OLS**	
Exposure Variables	OR	95% CI	beta	95% CI
Flush toilet				
Yes (ref)				
No	2.06	[1.76, 2.40]	-0.654	(-0.763, -0.546)
Toilet category				
High (ref)				
Intermediate	1.97	[1.69, 2.29]	-0.603	(-0.711, -0.500)
Poor	2.11	[1.78, 2.50]	-0.717	(-0.841, -0.592)
Piped water source				
Yes (ref)				
No	2.58	[2.09, 3.19]	-0.930	(-1.069, -0.792)
Drinking water category				
High (ref)				
Intermediate	1.90	[1.67, 2.17]	-0.578	(-0.670, -0.485)
Poor	2.31	[1.97, 2.71]	-0.745	(-0.864, -0.626)
Finished flooring				
Yes (ref)				
No	1.48	[1.37, 1.61]	-0.354	(-0.417, -0.291)
Floor type - binary				
Improved (ref)				
Unimproved	1.48	[1.37, 1.61]	-0.355	(-0.418, -0.292)
Ownership of cattle				
No (ref)				
Yes	0.93	[0.83, 1.03]	0.002	(-0.078, 0.083)
Ownership of chickens				
No (ref)				
Yes	1.09	[1.01, 1.18]	0.109	(0.050, 0.168)
Ownership of pigs				
No (ref)				
Yes	1.02	[0.90, 1.15]	-0.043	(-0.052, 0.137)
Own any sanitation animals (chickens, cattle, or pigs)				
No (ref)				
Yes	1.07	[0.99, 1.15]	-0.093	(-0.152, -0.034)
Share toilet with other households				
No (ref)				
Yes	1.06	[0.97, 1.15]	0.008	(-0.062, 0.077)

Any treatment of water				
Yes (ref)				
No	1.13	[1.04, 1.22]	0.171	(0.106, 0.236)
Treat water by boil				
Yes (ref)				
No	1.22	[1.08, 1.38]	-0.225	(-0.321, -0.130)
Treat water by bleach				
Yes (ref)				
No	1.07	[0.98, 1.17]	-0.108	(-0.179, -0.037)
Covariates				
Child gender				
Female (ref)				
Male	1.22	[1.13. 1.31]	-0.177	(-0.236, -0.118)
Child age	1.01	[1.01, 1.01]	-0.013	(-0.015, -0.012)
Child age category				
0-23 months (ref)				
24-60 months	1.37	[1.27, 1.48]	-0.450	(-0.509, -0.390)
Diarrhea in last 2 weeks				
No (ref)				
Yes	1.19	[1.08, 1.32]	-0.118	(-0.197, -0.039)
Wealth score	0.73	[0.70, 0.77]	0.266	(0.232, 0.299)
Household in wealthy quintiles				
Yes (ref)				
No	1.57	[1.44, 1.71]	-0.392	(-0.457, -0.327)
Household wealth quintile				
Richest (ref)				
Richer	1.60	[1.37, 1.86]	-0.415	(-0.526, -0.305)
Middle	1.76	[1.52, 2.03]	-0.538	(-0.641, -0.434)
Poorer	2.04	[1.77, 2.35]	-0.588	(-0.691, -0.485)
Poorest	2.47	[2.15, 2.85]	-0.767	(-0.870, -0.664)
Mother's years of education	1.02	[1.01, 1.04]	-0.019	(-0.034, -0.004)
Mother secondary education				
Yes (ref)				
No	1.44	[1.33, 1.56]	-0.31	(-0.371, -0.245)
Mother's education level				
Higher (ref)				
Secondary	2.75	[2.10, 3.61]	-0.748	(-0.855, -0.540)
Primary	3.58	[2.74, 4.68]	-0.965	(-1.128, -0.803)
No education	3.80	[2.86, 5.05]	-1.031	(-1.211, -0.851)
Child Dietary Diversity				
Adequate (score of 4+), (ref)				
Inadequate (scores less than 4)	0.91	[0.79, 1.05]	0.135	(0.019, 0.250)
Urban or rural location				
Urban (ref)				
Rural	1.30	[1.20, 1.41]	0.250	(0.188, 0.311)

Table 6A.9 Sensitivity analyses using multivariate logistic regression models of child stunting on improved or unimproved toilet type in Madagascar and Zambia in Aim 2

Variables	Madagascar Toilet Unadjusted		Madagascar Toilet Adjusted*		Zambia Toilet Unadjusted		Zambia Toilet Adjusted*	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Toilet type								
Improved (ref)								
Unimproved	1.26	[0.97, 1.63]	0.97	[0.74, 1.28]	1.37	[0.65, 2.88]	1.40	[0.66, 2.97]
Ownership of cattle, chicken or pigs								
No (ref)								
Yes	1.27	[1.06, 1.52]	1.03	[0.84, 1.25]	1.10	[1.01, 1.20]	0.94	[0.85, 1.03]
Share toilet								
No (ref)								
Yes	1.24	[1.04, 1.50]	1.33	[1.10, 1.61]	1.08	[0.98, 1.18]	1.11	[1.01, 1.22]

*Adjusted for household wealth, mother's education level, urban/rural location, and child age category

Table 6A.10 Sensitivity analyses using multivariate logistic regression models of child stunting on improved or unimproved drinking water in Madagascar and Zambia in Aim 2

Variables	Madagascar Water Unadjusted		Madagascar Water Adjusted*		Zambia Water Unadjusted		Zambia Water Adjusted*	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Drinking water source								
Improved (ref)								
Unimproved	1.02	[0.88, 1.18]	0.87	[0.73, 1.04]	1.29	[1.19, 1.40]	1.14	[1.04, 1.24]
Ownership of cattle, chicken or pigs								
No (ref)								
Yes	1.06	[0.91, 1.23]	0.95	[0.81, 1.11]	1.01	[0.93, 1.09]	0.91	[0.83, 0.99]
Treat drinking water								
Yes (ref)								
No	0.89	[0.77, 1.02]	0.85	[0.74, 0.98]	1.12	[1.03, 1.21]	1.00	[0.92, 1.09]

*Adjusted for household wealth, mother's education level, urban/rural location, and child age category

Table 7A.1 Descriptive characteristics of MDHS sample of children 0-59 months and reports of conflict occurrences within 50km, 100km, and 250km of the household by stunting outcome in Aim 3

Madagascar DHS 2008-2009			
Descriptive Statistics on Conflicts within 50km, 100km, and 250km of a Household by Stunting Outcome			
Predictors	**Non-stunted** (n=2,501)	**Stunted** (n=2,360)	**Total** (n=4,861)
Any conflicts that occurred within 50km of household during pregnancy			
No	1980 87.8%	1830 48.0%	3810
Yes	275 12.2%	305 14.3%	580
Any conflicts that occurred within 100km of household during pregnancy			
No	1715 76.1%	1491 48.0%	3206
Yes	540 23.9%	644 30.2%	1184
Any conflicts that occurred within 250km of household during pregnancy			
No	1045 46.3%	782 48.0%	1827
Yes	1210 53.7%	1353 63.4%	2563
Any conflicts that occurred within 50km of household during child's first year of life			
No	1897 84.1%	1794 48.0%	3691
Yes	358 15.9%	341 16.0%	699
Any conflicts that occurred within 100km of household during child's first year of life			
No	1623 72.0%	1446 48.0%	3069
Yes	632 28.0%	689 32.3%	1321
Any conflicts that occurred within 250km of household during child's first year of life			

No	870 38.6%	722 48.0%	1592
Yes	1385 47.40%	1413 52.60%	2798
Any fatal conflict events within 50km of household during pregnancy			
No	2099 93.1%	1961 48.0%	4060
Yes	156 6.9%	174 8.1%	330
Any fatal conflict events within 100km of household during pregnancy			
No	1946 86.3%	1796 48.0%	3742
Yes	309 13.7%	339 15.9%	648
Any fatal conflict events within 250km of household during pregnancy			
No	1481 65.7%	1281 48.0%	2762
Yes	774 34.3%	854 40.0%	1628
Any fatal conflict events within 50km of household during child's first year of life			
No	2010 89.1%	1876 48.0%	3886
Yes	245 10.9%	259 12.1%	504
Any fatal conflict events within 100km of household during child's first year of life			
No	1800 79.8%	1619 48.0%	3419
Yes	455 20.2%	516 24.2%	971
Any fatal conflict events within 250km of household during child's first year of life			
No	1090 48.3%	928 48.0%	2018
Yes	1165 51.7%	1207 56.5%	2372
Any battles that occurred within 50km of household during pregnancy			
No	914	999	1913

	96.6%	48.0%	
Yes	32 3.4%	23 2.3%	55
Any battles that occurred within 100km of household during pregnancy			
No	1515 94.0%	1599 48.0%	3114
Yes	97 6.0%	94 5.6%	191
Any battles that occurred within 250km of household during pregnancy			
No	1876 84.6%	1763 48.0%	3639
Yes	342 15.4%	334 15.9%	676
Any riots/protests that occurred within 50km of household during pregnancy			
No	768 81.2%	811 48.0%	1579
Yes	178 18.8%	211 20.6%	389
Any riots/protests that occurred within 100km of household during pregnancy			
No	1262 78.3%	1270 48.0%	2532
Yes	350 21.7%	423 25.0%	773
Any riots/protests that occurred within 250km of household during pregnancy			
No	1315 59.3%	1062 48.0%	2377
Yes	903 40.7%	1035 49.4%	1938
Any violence against civilians that occurred within 50km of household during pregnan cy			
No	745 78.8%	797 48.0%	1542
Yes	201 21.2%	225 22.0%	426
Any violence against civilians that occurred within 100km of household during pregna ncy			
No	1226 76.1%	1239 48.0%	2465
Yes	386	454	840

	23.9%	26.8%	
Any violence against civilians that occurred within 250km of household during pregna ncy			
No	1241 56.0%	977 48.0%	2218
Yes	977 44.0%	1120 53.4%	2097
Any battles that occurred within 50km of household during first year of child's life			
No	863 91.2%	969 48.0%	1832
Yes	83 8.8%	53 5.2%	136
Any battles that occurred within 100km of household during first year of child's life			
No	1432 88.8%	1522 48.0%	2954
Yes	180 11.2%	171 10.1%	351
Any battles that occurred within 250km of household during first year of child's life			
No	1640 73.9%	1493 48.0%	3133
Yes	578 26.1%	604 28.8%	1182
Any riots/protests that occurred within 50km of household during first year of child's l ife			
No	696 73.6%	764 48.0%	1460
Yes	250 26.4%	258 25.2%	508
Any riots/protests that occurred within 100km of household during first year of child's life			
No	1174 72.8%	1205 48.0%	2379
Yes	438 27.2%	488 28.8%	926
Any riots/protests that occurred within 250km of household during first year of child's life			
No	1070 48.2%	925 48.0%	1995
Yes	1148 51.8%	1172 55.9%	2320

Any violence against civilians that occurred within 50km of household during during f irst year of child's life			
No	704 74.4%	789 48.0%	1493
Yes	242 25.6%	233 22.8%	475
Any violence against civilians that occurred within 100km of household during during first year of child's life			
No	1168 72.5%	1228 48.0%	2396
Yes	444 27.5%	465 27.5%	909
Any violence against civilians that occurred within 250km of household during during first year of child's life			
No	1107 49.9%	944 48.0%	2051
Yes	1111 50.1%	1153 55.0%	2264
Covariates	**Non-stunted** (n=2,501)	**Stunted** (n=2,360)	**Total** (n=4,861)
Wealthy or wealthiest quintile households			
No	1649 65.9%	1625 48.0%	3274
Yes	852 34.1%	735 31.1%	1587
Urban or rural location			
Urban	509 20.4%	371 48.0%	880
Rural	1992 79.6%	1989 84.3%	3981
Child Dietary Diversity Adequacy			
Inadequate	1731 84.7%	1583 48.0%	3314
Adequate	312 15.3%	302 16.0%	614
Low birthweight			
Normal	947 90.5%	782 48.0%	1729
Low birthweight	99 9.5%	121 13.4%	220

Table 7A.2 Descriptive characteristics of ZDHS sample of children 0-59 months and reports of conflict occurrences within 50km, 100km, and 250km of the household by stunting outcome

Zambia DHS 2013-2014			
Descriptive Statistics on Conflicts within 50km, 100km, and 250km of a Household by Stunting Outcome			
Predictors	**Non-stunted** (n=6,858)	**Stunted** (n=4,549)	**Total** (n=11,407)
Any conflicts that occurred within 50km of household during pregnancy			
No	3596 72.5%	2571 77.4%	6167
Yes	1362 27.5%	752 22.6%	2114
Any conflicts that occurred within 100km of household during pregnancy			
No	2818 56.8%	2066 62.2%	4884
Yes	2140 43.2%	1257 37.8%	3397
Any conflicts that occurred within 250km of household during pregnancy			
No	975 19.7%	776 23.4%	1751
Yes	3983 80.3%	2547 76.6%	6530
Any conflicts that occurred within 50km of household during child's first year of lif e			
No	3299 66.5%	2323 69.9%	5622
Yes	1659 33.5%	1000 30.1%	2659
Any conflicts that occurred within 100km of household during child's first year of life			
No	2324 46.9%	1725 51.9%	4049
Yes	2634 53.1%	1598 48.1%	4232
Any conflicts that occurred within 250km of household during child's first year of life			
No	560	416	976

	11.3%	12.5%	
Yes	4398	2907	7305
	88.7%	87.5%	
Any fatal conflict events within 50km of household during pregnancy			
No	4362	3016	7378
	88.0%	90.8%	
Yes	596	307	903
	12.0%	9.2%	
Any fatal conflict events within 100km of household during pregnancy			
No	3692	2611	6303
	79.0%	82.9%	
Yes	979	539	1518
	21.0%	17.1%	
Any fatal conflict events within 250km of household during pregnancy			
No	2900	2206	5106
	58.5%	66.4%	
Yes	2058	1117	3175
	41.5%	33.6%	
Any fatal conflict events within 50km of household during child's first year of life			
No	4239	2888	7127
	85.5%	86.9%	
Yes	719	435	1154
	14.5%	13.1%	
Any fatal conflict events within 100km of household during child's first year of life			
No	3497	2396	5893
	74.9%	76.1%	
Yes	1174	754	1928
	25.1%	23.9%	
Any fatal conflict events within 250km of household during child's first year of life			
No	2413	1755	4168
	48.7%	52.8%	
Yes	2545	1568	4113
	51.3%	47.2%	
Any fatal conflict events within 50km of household during child's first 2 years of life			
No	3964	2682	6646
	80.0%	80.7%	
Yes	994	641	1635

	20.0%	19.3%	
Any fatal conflict events within 100km of household during child's first 2 years of life			
No	3091 66.2%	2103 66.8%	5194
Yes	1580 33.8%	1047 33.2%	2627
Any fatal conflict events within 250km of household during child's first 2 years of life			
No	1916 38.6%	1292 38.9%	3208
Yes	3042 61.4%	2031 61.1%	5073
Any battles that occurred within 50km of household during pregnancy			
No	3580 95.6%	2406 96.2%	5986
Yes	163 4.4%	95 3.8%	258
Any battles that occurred within 100km of household during pregnancy			
No	4397 94.1%	2987 94.8%	7384
Yes	274 5.9%	163 5.2%	437
Any battles that occurred within 250km of household during pregnancy			
No	4105 83.1%	2824 85.3%	6929
Yes	833 16.9%	488 14.7%	1321
Any riots/protests that occurred within 50km of household during pregnancy			
No	2603 69.5%	1872 74.9%	4475
Yes	1140 30.5%	629 25.1%	1769
Any riots/protests that occurred within 100km of household during pregnancy			
No	2838 60.8%	2095 66.5%	4933
Yes	1833 39.2%	1055 33.5%	2888

Any riots/protests that occurred within 250km of household during pregnancy			
No	1215 24.6%	1000 30.2%	2215
Yes	3723 75.4%	2312 69.8%	6035
Any violence against civilians that occurred within 50km of household during preg nancy			
No	2969 79.3%	2088 83.5%	5057
Yes	774 20.7%	413 16.5%	1187
Any violence against civilians that occurred within 100km of household during pre gnancy			
No	3347 71.7%	2417 76.7%	5764
Yes	1324 28.3%	733 23.3%	2057
Any violence against civilians that occurred within 250km of household during pre gnancy			
No	2257 45.7%	1727 52.1%	3984
Yes	2681 54.3%	1585 47.9%	4266
Any battles that occurred within 50km of household during first year of child's life			
No	3404 90.9%	2343 93.7%	5747
Yes	339 9.1%	158 6.3%	497
Any battles that occurred within 100km of household during first year of child's life			
No	4162 89.1%	2904 92.2%	7066
Yes	509 10.9%	246 7.8%	755
Any battles that occurred within 250km of household during first year of child's life			
No	3633 73.6%	2567 77.5%	6200
Yes	1305 26.4%	745 22.5%	2050
Any riots/protests that occurred within 50km of household during first year of child 's life			

No	2394 64.0%	1697 67.9%	4091
Yes	1349 36.0%	804 32.1%	2153
Any riots/protests that occurred within 100km of household during first year of child's life			
No	2481 53.1%	1808 57.4%	4289
Yes	2190 46.9%	1342 42.6%	3532
Any riots/protests that occurred within 250km of household during first year of child's life			
No	811 16.4%	619 18.7%	1430
Yes	4127 83.6%	2693 81.3%	6820
Any violence against civilians that occurred within 50km of household during during first year of child's life			
No	2758 73.7%	1943 77.7%	4701
Yes	985 26.3%	558 22.3%	1543
Any violence against civilians that occurred within 100km of household during during first year of child's life			
No	2937 62.9%	2166 68.8%	5103
Yes	1734 37.1%	984 31.2%	2718
Any violence against civilians that occurred within 250km of household during during first year of child's life			
No	1655 33.5%	1378 41.6%	3033
Yes	3283 66.5%	1934 58.4%	5217
Covariates	**Non-stunted** (n=6,858)	**Stunted** (n=4,549)	**Total** (n=11,407)
Wealthy or wealthiest quintile households			
No	4633 67.6%	3484 76.6%	8117

Yes	2225 32.4%	1065 23.4%	3290
Urban or rural location			
Urban	2647 38.6%	1482 32.6%	4129
Rural	4211 61.4%	3067 67.4%	7278
Child Dietary Diversity Adequacy			
Inadequate	3720 86.6%	2280 85.5%	6000
Adequate	575 13.4%	387 14.5%	962
Low birthweight			
Normal	4495 94.4%	2510 87.5%	7005
Low birthweight	267 5.6%	360 12.5%	627

Table 7A.3 Madagascar Tetrachoric Correlation Table in Aim 3

	Stunting	100K preg conflict	100K first year conflict	100K fatal preg	100K fatal first year	100K battle preg	100K battle first year	100K riot preg	100K riot first year	100K viol civ preg	100K viol civ first year	Wealthy household	Urban/rural	Low birthweight	Dietary diversity
Stunting	-	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.0	-0.1	0.1	0.1	0.0
100K preg conflict	0.1	-	0.7	1.0	0.6	1.0	0.1	1.0	0.5	1.0	0.7	0.4	-0.3	0.1	0.3
100K first year conflict	0.1	0.7	-	0.7	1.0	0.1	1.0	0.7	1.0	0.6	1.0	0.4	-0.3	0.0	0.2
100K fatal preg	0.1	1.0	0.7	-	0.6	0.6	0.0	0.9	0.5	0.8	0.7	0.4	-0.2	0.0	0.2
100K fatal first year	0.1	0.6	1.0	0.6	-	-0.1	0.6	0.7	1.0	0.6	0.9	0.4	-0.3	0.0	0.1
100K battle preg	0.0	1.0	0.1	0.6	-0.1	-	0.1	0.1	0.0	0.2	-0.2	0.0	0.1	0.0	-0.1
100K battle first year	0.0	0.1	1.0	0.0	0.6	0.1	-	0.0	0.3	0.1	0.3	0.1	0.0	0.1	-0.2
100K riot preg	0.1	1.0	0.7	0.9	0.7	0.1	0.0	-	0.7	0.8	0.8	0.4	-0.2	0.0	0.3
100K riot first year	0.0	0.5	1.0	0.5	1.0	0.0	0.3	0.7	-	0.5	0.9	0.4	-0.3	0.0	0.1
100K viol civ preg	0.1	1.0	0.6	0.8	0.6	0.2	0.1	0.8	0.5	-	0.7	0.3	-0.2	0.1	0.2
100K viol civ first year	0.0	0.7	1.0	0.7	0.9	-0.2	0.3	0.8	0.9	0.7	-	0.4	-0.3	0.0	0.2
Wealthy household	-0.1	0.4	0.4	0.4	0.4	0.0	0.1	0.4	0.4	0.3	0.4	-	-0.8	0.0	0.5
Urban/rural	0.1	-0.3	-0.3	-0.2	-0.3	0.1	0.0	-0.2	-0.3	-0.2	-0.3	-0.8	-	0.0	-0.4
Low birthweight	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	-	0.0
Dietary diversity	0.0	0.3	0.2	0.2	0.1	-0.1	-0.2	0.3	0.1	0.2	0.2	0.5	-0.4	0.0	-

Table 7A.4 Madagascar Pearson Correlation Table in Aim 3

	Child HAZ	100K preg # conflicts	100K first year # conflicts	100K fatal preg #	100K fatal first year #	100K battle preg #	100K battle first year #	100K riot preg #	100K riot first year #	100K viol civ preg #	100K viol civ first year #	Wealth quintile	Urban/rural	Birthweight	Dietary diversity score
Child HAZ	-	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-0.1	0.0	0.0	0.0	0.1	-0.1
100K preg # conflicts	-0.1	-	0.2	0.7	0.2	0.1	0.1	0.9	0.1	0.7	0.3	0.2	-0.1	0.0	0.1
100K first year # conflicts	0.0	0.2	-	0.2	0.7	0.1	0.4	0.1	0.7	0.2	0.6	0.2	-0.1	0.0	0.0
100K fatal preg #	0.0	0.7	0.2	-	0.1	0.3	0.1	0.6	0.0	0.4	0.2	0.2	-0.1	0.0	0.1
100K fatal first year #	0.0	0.2	0.7	0.1	-	0.0	0.7	0.2	1.0	0.1	0.9	0.2	-0.1	0.0	-0.1
100K battle preg #	0.0	0.1	0.1	0.3	0.0	-	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
100K battle first year #	0.0	0.1	0.4	0.1	0.7	0.0	-	0.1	0.6	0.0	0.6	0.1	0.0	0.0	-0.2
100K riot preg #	0.0	0.9	0.1	0.6	0.2	0.0	0.1	-	0.1	0.5	0.3	0.2	-0.1	0.0	0.0
100K riot first year #	0.1	0.1	0.7	0.0	1.0	0.0	0.6	0.1	-	0.0	0.9	0.2	-0.1	0.0	-0.1
100K viol civ preg #	-0.1	0.7	0.2	0.4	0.1	0.1	0.0	0.5	0.0	-	0.1	0.2	-0.1	0.0	0.1
100K viol civ first year #	0.0	0.3	0.6	0.2	0.9	0.0	0.6	0.3	0.9	0.1	-	0.2	-0.1	-0.1	-0.1
Wealth quintile	0.0	0.2	0.2	0.2	0.2	0.0	0.1	0.2	0.2	0.2	0.2	-	-0.7	0.1	0.3
Urban/rural	0.0	-0.1	-0.1	-0.1	-0.1	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.7	-	0.0	-0.2
Birthweight	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.1	0.0	-	0.0
Dietary diversity score	-0.1	0.1	0.0	0.1	-0.1	0.0	-0.2	0.0	-0.1	0.1	-0.1	0.3	-0.2	0.0	-

Table 7A.4 Zambia Tetrachoric Correlation Table in Aim 3

	Stunting	100K preg conflict	100K first year conflict	100K fatal preg	100K fatal first year	100K battle preg	100K battle first year	100K riot preg	100K riot first year	100K viol civ preg	100K viol civ first year	Wealthy household	Urban/rural	Low birthweight	Dietary diversity
Stunting	-	-0.1	0.0	-0.1	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	0.1	0.3	0.0
100K preg conflict	-0.1	-	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0	0.6	0.4	-0.2	0.0	0.0
100K first year conflict	0.0	0.7	-	0.8	1.0	0.7	1.0	0.7	1.0	0.7	1.0	0.4	-0.2	0.0	0.1
100K fatal preg	-0.1	1.0	0.8	-	0.8	0.8	0.7	0.9	0.8	0.9	0.9	0.5	-0.3	0.0	0.1
100K fatal first year	0.0	0.7	1.0	0.8	-	0.7	0.8	0.7	0.8	0.8	0.9	0.5	-0.3	0.1	0.2
100K battle preg	0.0	1.0	0.7	0.8	0.7	-	0.5	0.8	0.7	0.8	0.6	0.4	-0.2	0.1	0.0
100K battle first year	-0.1	0.7	1.0	0.7	0.8	0.5	-	0.7	0.8	0.7	0.8	0.5	-0.3	0.1	0.1
100K riot preg	-0.1	1.0	0.7	0.9	0.7	0.8	0.7	-	0.7	0.8	0.7	0.4	-0.3	0.0	0.1
100K riot first year	-0.1	0.7	1.0	0.8	0.8	0.7	0.8	0.7	-	0.6	0.7	0.4	-0.2	0.0	0.1
100K viol civ preg	-0.1	1.0	0.7	0.9	0.8	0.8	0.7	0.8	0.6	-	0.7	0.4	-0.2	0.0	0.0
100K viol civ first year	-0.1	0.6	1.0	0.9	0.9	0.6	0.8	0.7	0.7	0.7	-	0.3	-0.2	0.1	0.1
Wealthy household	-0.2	0.4	0.4	0.5	0.5	0.4	0.5	0.4	0.4	0.4	0.3	-	-0.8	0.0	0.3
Urban/rural	0.1	-0.2	-0.2	-0.3	-0.3	-0.2	-0.3	-0.3	-0.2	-0.2	-0.2	-0.8	-	0.0	-0.2
Low birthweight	0.3	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	-	0.0
Dietary diversity	0.0	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.1	0.0	0.1	0.3	-0.2	0.0	-

Table 7A.5 Zambia Pearson Correlation Table

	Child HAZ	100K preg # conflicts	100K first year # conflicts	100K fatal preg #	100K fatal first year #	100K battle preg #	100K battle first year #	100K riot preg #	100K riot first year #	100K viol civ preg #	100K viol civ first year #	Wealth quintile	Urban/rural	Birthweight	Dietary diversity score
Child HAZ	-	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	-0.1	0.1	-0.1
100K preg # conflicts	0.1	-	0.7	0.7	0.8	0.2	0.5	1.0	0.8	0.9	0.8	0.3	-0.2	0.0	-0.1
100K first year # conflicts	0.1	0.7	-	0.6	0.8	0.6	0.5	0.7	0.9	0.6	0.9	0.3	-0.2	0.0	0.1
100K fatal preg #	0.1	0.7	0.6	-	0.5	0.3	0.4	0.7	0.6	0.7	0.5	0.3	-0.1	0.0	0.0
100K fatal first year #	0.1	0.8	0.8	0.5	-	0.2	0.5	0.8	0.8	0.6	0.8	0.3	-0.2	-0.1	0.0
100K battle preg #	0.0	0.2	0.6	0.3	0.2	-	0.1	0.2	0.5	0.2	0.3	0.2	-0.1	0.0	0.0
100K battle first year #	0.1	0.5	0.5	0.4	0.5	0.1	-	0.5	0.4	0.5	0.4	0.2	-0.1	0.0	0.0
100K riot preg #	0.1	1.0	0.7	0.7	0.8	0.2	0.5	-	0.8	0.9	0.8	0.3	-0.2	0.0	0.0
100K riot first year #	0.1	0.8	0.9	0.6	0.8	0.5	0.4	0.8	-	0.6	0.9	0.3	-0.2	0.0	0.1
100K viol civ preg #	0.1	0.9	0.6	0.7	0.6	0.2	0.5	0.9	0.6	-	0.6	0.2	-0.1	0.0	-0.1
100K viol civ first year #	0.1	0.8	0.9	0.5	0.8	0.3	0.4	0.8	0.9	0.6	-	0.3	-0.1	0.0	0.0
Wealth quintile	0.1	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.3	-	-0.6	0.0	0.1
Urban/rural	-0.1	-0.2	-0.2	-0.1	-0.2	-0.1	-0.1	-0.2	-0.2	-0.1	-0.1	-0.6	-	0.1	-0.1
Birthweight	0.1	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-	0.0
Dietary diversity score	-0.1	-0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	-0.1	0.0	0.1	-0.1	0.0	-

Table 7A.6 Bivariate logistic and linear regression models of conflict occurrences within 50km, 100km, and 250km by stunting and height-for-age z-score outcome in Madagascar in Aim 3

	Stunting outcome n = 4,861		Height-for-age z-score n = 4,861	
	Logistic		OLS	
Exposure Variables	OR	95% CI	beta	95% CI
Pregnancy conflicts within 50km				
No (ref)				
Yes	1.17	[0.68, 2.01]	-0.224	(-0.571, 0.123)
Pregnancy conflicts within 100km				
No (ref)				
Yes	1.13	[0.74, 1.72]	0.013	(-0.024, 0.051)
Pregnancy conflicts within 250km				
No (ref)				
Yes	1.18	[0.88, 1.58]	0.020	(0.002, 0.037)
Fatal conflicts preg within 50km				
No (ref)				
Yes	1.57	[0.79, 3.10]	-0.062	(-0.519, 0.395)
Fatal conflicts preg within 100km				
No (ref)				
Yes	1.17	[0.72, 1.91]	0.064	(-0.179, 0.306)
Fatal conflicts preg within 250km				
No (ref)				
Yes	1.27	[0.94, 1.73]	0.074	(-0.034, 0.183)
Battle during pregnancy within 50km				
No (ref)				
Yes	0.49	[0.18, 1.34]	0.205	(-0.647, 1.056)
Battle during pregnancy within 100km				
No (ref)				
Yes	0.53	[0.26, 1.09]	0.373	(-0.229, 0.975)
Battle during pregnancy within 250km				
No (ref)				
Yes	0.98	[0.68, 1.40]	-0.107	(-0.464, 0.251)

Riot/protest during pregnancy within 50km				
No (ref)				
Yes	3.16	[1.13, 8.87]	-0.271	(-0.806, 0.264)
Riot/protest during pregnancy within 100km				
No (ref)				
Yes	1.47	[0.77, 2.83]	0.023	(-0.020, 0.066)
Riot/protest during pregnancy within 250km				
No (ref)				
Yes	1.24	[0.86, 1.77]	0.024	(0.003, 0.046)
Violence against civilians during pregnancy within 50km				
No (ref)				
Yes	0.65	[0.31, 1.38]	-0.153	(-0.836, 0.530)
Violence against civilians during pregnancy within 100km				
No (ref)				
Yes	0.62	[0.33, 1.15]	0.100	(-0.131, 0.332)
Violence against civilians during pregnancy within 250km				
No (ref)				
Yes	0.82	[0.57, 1.20]	0.130	(0.010, 0.250)
First year of life conflicts within 50km				
No (ref)				
Yes	1.42	[1.04, 1.94]	-0.004	(-0.010, 0.002)
First year of life conflicts within 100km				
No (ref)				
Yes	1.62	[1.23, 2.12]	-0.005	(-0.010, 0.000)
First year of life conflicts within 250km				
No (ref)				
Yes	1.29	[0.96, 1.73]	0.000	(-0.003, 0.002)
Fatal conflicts first within 50km				
No (ref)				
Yes	1.59	[1.13, 2.24]	-0.035	(-0.079, 0.010)
Fatal conflicts first within 100km				
No (ref)				
Yes	1.58	[1.19, 2.09]	-0.040	(-0.076, -0.005)

Fatal conflicts first within 250km				
No (ref)				
Yes	1.26	[0.95, 1.68]	-0.006	(-0.025, 0.014)
Battle during first year within 50km				
No (ref)				
Yes	0.70	[0.40, 1.23]	0.268	(-0.053, 0.590)
Battle during first year within 100km				
No (ref)				
Yes	1.00	[0.67, 1.47]	0.072	(-0.123, 0.266)
Battle during first year within 250km				
No (ref)				
Yes	1.41	[1.08, 1.85]	0.031	(-0.074, 0.136)
Riot/protest during first year within 50km				
No (ref)				
Yes	1.22	[0.82, 1.84]	-0.003	(-0.011, 0.005)
Riot/protest during first year within 100km				
No (ref)				
Yes	1.22	[0.89, 1.66]	-0.003	(-0.009, 0.003)
Riot/protest during first year within 250km				
No (ref)				
Yes	1.08	[0.82, 1.43]	-0.001	(-0.005, 0.003)
Violence against civilians during first year within 50km				
No (ref)				
Yes	1.61	[1.07, 2.44]	-0.014	(-0.056, 0.029)
Violence against civilians during first year within 100km				
No (ref)				
Yes	1.62	[1.19, 2.22]	-0.013	(-0.044, 0.018)
Violence against civilians during first year within 250km				
No (ref)				
Yes	1.40	[1.07, 1.84]	-0.001	(-0.019, 0.017)
Covariates				
Wealth score	0.85	[0.79, 0.91]	0.100	(0.037, 0.162)
Household in wealthiest quintiles				

Yes (ref)				
No	1.14	[1.01, 1.29]	-0.049	(-0.163, 0.064)
Household wealth quintile				
Richest (ref)				
Richer	1.72	[1.41, 2.09]	-0.473	(-0.659, -0.287)
Middle	1.67	[1.37, 2.03]	-0.378	(-0.561, -0.194)
Poorer	1.60	[1.32, 1.93]	-0.324	(-0.500, -0.148)
Poorest	1.36	[1.14, 1.63]	-0.213	(-0.379, -0.047)
Urban or rural location				
Urban (ref)				
Rural	1.37	[1.18, 1.59]	0.193	(0.054, 0.331)
Birthweight	0.73	[0.63, 0.84]	0.256	(0.124, 0.388)
Birthweight status				
Normal (ref)				
Low	1.48	[1.17, 1.96]	-0.391	(-0.654, -0.129)
Child dietary diversity	1.08	[1.04, 1.13]	-0.080	(-0.122, -0.038)
Adequate child dietary diversity				
Adequate (score of 4+), (ref)				
Inadequate (scores less than 4)	0.95	[0.80, 1.12]	0.074	(-0.095, 0.243)

Table 7A.7 Bivariate logistic and linear regression models of conflict occurrences within 50km, 100km, and 250km by stunting and height-for-age z-score outcome in Zambia in Aim 3

	Stunting outcome n = 11,407		**Height-for-age z-score n = 11,407**	
	Logistic		**OLS**	
Exposure Variables	OR	95% CI	beta	95% CI
Pregnancy conflicts within 50km				
No (ref)				
Yes	0.77	[0.70, 0.86]	0.021	(0.016, 0.025)
Pregnancy conflicts within 100km				
No (ref)				
Yes	0.90	[0.73, 1.12]	0.010	(0.005, 0.015)
Pregnancy conflicts within 250km				

No (ref)				
Yes	0.75	[0.50, 1.15]	0.002	(-0.001, 0.004)
Fatal conflicts preg within 50km				
No (ref)				
Yes	0.75	[0.64, 0.86]	0.090	(0.051, 0.130)
Fatal conflicts preg within 100km				
No (ref)				
Yes	0.96	[0.76, 1.20]	0.096	(0.020, 0.172)
Fatal conflicts preg within 250km				
No (ref)				
Yes	0.88	[0.71, 1.10]	0.014	(-0.016, 0.044)
Battle during pregnancy within 50km				
No (ref)				
Yes	0.87	[0.67, 1.12]	0.011	(-0.095, 0.117)
Battle during pregnancy within 100km				
No (ref)				
Yes	0.60	[0.34, 0.95]	-0.005	(-0.243, 0.233)
Battle during pregnancy within 250km				
No (ref)				
Yes	0.87	[0.69, 1.11]	-0.006	(-0.120, 0.109)
Riot/protest during pregnancy within 50km				
No (ref)				
Yes	0.77	[0.69, 0.86]	0.029	(0.022, 0.036)
Riot/protest during pregnancy within 100km				
No (ref)				
Yes	0.81	[0.65, 1.00]	0.014	(0.006, 0.023)
Riot/protest during pregnancy within 250km				
No (ref)				
Yes	0.80	[0.58, 1.10]	0.001	(-0.004, 0.006)
Violence against civilians during pregnancy within 50km				
No (ref)				
Yes	0.76	[0.67, 0.87]	0.077	(0.060, 0.094)
Violence against civilians during pregnancy within 100km				
No (ref)				
Yes	0.89	[0.71, 1.11]	0.045	(0.026, 0.064)

Violence against civilians during pregnancy within 250km				
No (ref)				
Yes	0.88	[0.70, 1.11]	0.012	(0.002, 0.021)
First year of life conflicts within 50km				
No (ref)				
Yes	0.86	[0.78, 0.94]	0.013	(0.009, 0.016)
First year of life conflicts within 100km				
No (ref)				
Yes	0.99	[0.79, 1.24]	0.006	(0.002, 0.011)
First year of life conflicts within 250km				
No (ref)				
Yes	1.26	[0.62, 2.54]	0.000	(-0.003, 0.002)
Fatal conflicts first within 50km				
No (ref)				
Yes	0.89	[0.78, 1.01]	0.095	(0.063, 0.127)
Fatal conflicts first within 100km				
No (ref)				
Yes	0.95	[0.75, 1.20]	0.061	(0.018, 0.104)
Fatal conflicts first within 250km				
No (ref)				
Yes	1.09	[0.87, 1.36]	-0.013	(-0.038, 0.013)
Battle during first year within 50km				
No (ref)				
Yes	0.68	[0.56, 0.82]	0.252	(-0.176, 0.328)
Battle during first year within 100km				
No (ref)				
Yes	0.67	[0.49, 0.93]	0.243	(0.129, 0.357)
Battle during first year within 250km				
No (ref)				
Yes	0.88	[0.71, 1.09]	0.056	(-0.009, 0.120)
Riot/protest during first year within 50km				
No (ref)				
Yes	0.84	[0.76, 0.94]	0.019	(0.013, 0.025)
Riot/protest during first year within 100km				
No (ref)				

Yes	0.88	[0.71, 1.10]	0.012	(0.004, 0.021)
Riot/protest during first year within 250km				
No (ref)				
Yes	1.32	[0.82, 2.13]	0.000	(-0.005, 0.004)
Violence against civilians during first year within 50km				
No (ref)				
Yes	0.80	[0.71, 0.91]	0.044	(0.031, 0.057)
Violence against civilians during first year within 100km				
No (ref)				
Yes	0.94	[0.75, 1.16]	0.017	(-0.000, 0.033)
Violence against civilians during first year within 250km				
No (ref)				
Yes	0.95	[0.71, 1.25]	-0.005	(-0.014, 0.004)
Covariates				
Wealth score	0.73	[0.70, 0.77]	0.266	(0.232, 0.300)
Household in wealthiest quintiles				
Yes (ref)				
No	1.57	[1.44, 1.71]	-0.392	(-0.457, -0.327)
Household wealth quintile				
Richest (ref)				
Richer	1.60	[1.37, 1.86]	-0.415	(-0.526, -0.305)
Middle	1.76	[1.52, 2.03]	-0.538	(-0.641, -0.434)
Poorer	2.04	[1.77, 2.35]	-0.588	(-0.691, -0.485)
Poorest	2.47	[2.15, 2.85]	-0.767	(-0.870, -0.664)
Urban or rural location				
Urban (ref)				
Rural	1.30	[1.20, 1.41]	0.250	(0.188, 0.311)
Birthweight	0.62	[0.57, 0.67]	0.355	(0.295, 0.415)
Birthweight status				
Normal (ref)				
Low	2.41	[2.05, 2.85]	-0.608	(-0.741, -0.476)
Child dietary diversity	1.09	[1.06, 1.12]	-0.094	(-0.119, -0.068)
Adequate child dietary diversity				
Adequate (score of 4+), (ref)				
Inadequate (scores less than 4)	0.91	[0.79, 1.05]	0.135	(0.019, 0.250)

Table 7A.8 Multivariate logistic regression models of armed conflict exposures within 50, 100, and 250km during pregnancy and child stunting outcome in Madagascar and Zambia in Aim 3

	Madagascar Unadjusted		Madagascar Adjusted*		Zambia Unadjusted		Zambia Adjusted*	
Exposures	**Model 1**		**Model 2**		**Model 3**		**Model 4**	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Conflicts within 50km during pregnancy								
No (ref)								
Yes	1.20	[1.01, 1.43]	1.42	[1.05, 1.91]	0.77	[0.70, 0.86]	0.87	[0.73, 1.03]
Conflicts within 100km during pregnancy								
No (ref)								
Yes	1.37	[1.20, 1.57]	1.43	[1.13, 1.82]	0.80	[0.73, 0.88]	0.82	[0.71, 0.96]
Conflicts within 250km during pregnancy								
No (ref)								
Yes	1.49	[1.32, 1.69]	1.32	[1.05, 1.67]	0.80	[0.72, 0.89]	0.84	[0.69, 1.01]
Fatal conflicts within 50km during pregnancy								
No (ref)								
Yes	1.19	[0.95, 1.50]	1.65	[1.15, 2.37]	0.75	[0.64, 0.86]	0.88	[0.70, 1.10]
Fatal conflicts within 100km during pregnancy								
No (ref)								
Yes	1.19	[1.01, 1.41]	1.32	[1.00, 1.73]	0.71	[0.65, 0.78]	0.87	[0.72, 1.04]
Fatal conflicts within 250km during pregnancy								
No (ref)								
Yes	1.28	[1.13, 1.44]	1.19	[0.95, 1.49]	0.78	[0.69, 0.88]	0.74	[0.63, 0.85]
Battles within 50km during pregnancy								
No (ref)								
Yes	0.66	[0.38, 1.13]	0.51	[0.20, 1.27]	0.87	[0.67, 1.12]	0.89	[0.61, 1.30]
Battles within 100km during pregnancy								
No (ref)								
Yes	0.92	[0.69, 1.23]	0.89	[0.57, 1.39]	0.88	[0.72, 1.07]	0.94	[0.69, 1.26]
Battles within 250km during pregnancy								

No (ref)								
Yes	1.04	[0.88, 1.23]	1.20	[0.92, 1.56]	0.85	[0.75, 0.96]	0.85	[0.70, 1.03]
Riots/protests within 50km during pregnancy								
No (ref)								
Yes	1.12	[0.90, 1.40]	1.77	[1.23, 2.56]	0.77	[0.69, 0.86]	0.85	[0.70, 1.02]
Riots/protests within 100km during pregnancy								
No (ref)								
Yes	1.20	[1.02, 1.41]	1.27	[0.97, 1.66]	0.78	[0.71, 0.86]	0.79	[0.68, 0.93]
Riots/protests within 250km during pregnancy								
No (ref)								
Yes	1.42	[1.26, 1.60]	1.27	[1.01, 1.59]	0.76	[0.68, 0.83]	0.78	[0.66, 0.93]
Violence against civilians within 50km during pregnancy								
No (ref)								
Yes	1.05	[0.84, 1.30]	1.18	[0.83, 1.68]	0.76	[0.67, 0.87]	0.82	[0.67, 1.01]
Violence against civilians within 100km during pregnancy								
No (ref)								
Yes	1.16	[0.99, 1.36]	1.11	[0.85, 1.46]	0.77	[0.69, 0.85]	0.85	[0.72, 1.01]
Violence against civilians within 250km during pregnancy								
No (ref)								
Yes	1.46	[1.29, 1.64]	1.24	[0.99, 1.56]	0.77	[0.71, 0.84]	0.82	[0.71, 0.96]

*Adjusted for wealthy households, urban/rural location, low birthweight, and child dietary diversity

Table 7A.9 Multivariate logistic regression models of armed conflict exposures within 50, 100, and 250km during a child's first year and child stunting outcome in Madagascar and Zambia in Aim 3

	Madagascar Unadjusted		Madagascar Adjusted*		Zambia Unadjusted		Zambia Adjusted*	
Exposures	**Model 1**		**Model 2**		**Model 3**		**Model 4**	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Conflicts within 50km during child's first year								
No (ref)								
Yes	1.00	[0.82, 1.21]	1.39	[0.99, 1.96]	0.95	[0.85, 1.06]	0.93	[0.80, 1.09]
Conflicts within 100km during child's first year								
No (ref)								
Yes	1.21	[1.04, 1.40]	1.23	[0.93, 1.62]	0.93	[0.84, 1.03]	0.84	[0.72, 0.98]
Conflicts within 250km during child's first year								
No (ref)								
Yes	1.32	[1.15, 1.52]	1.32	[1.01, 1.73]	1.06	[0.92, 1.22]	0.89	[0.69, 1.16]
Fatal conflicts within 50km during child's first year								
No (ref)								
Yes	1.14	[0.91, 1.43]	1.67	[1.14, 2.45]	0.89	[0.77, 1.03]	1.00	[0.81, 1.22]
Fatal conflicts within 100km during child's first year								
No (ref)								
Yes	1.32	[1.11, 1.56]	1.38	[1.02, 1.87]	1.00	[0.89, 1.13]	0.95	[0.80, 1.13]
Fatal conflicts within 250km during child's first year								
No (ref)								
Yes	1.39	[1.22, 1.59]	1.44	[1.11, 1.88]	0.97	[0.88, 1.07]	0.93	[0.80, 1.07]

Battles within 50km during child's first year								
No (ref)								
Yes	0.73	[0.45, 1.19]	0.43	[0.18, 1.04]	0.82	[0.65, 1.03]	0.59	[0.44, 0.79]
Battles within 100km during child's first year								
No (ref)								
Yes	1.06	[0.80, 1.41]	0.49	[0.29, 0.83]	0.84	[0.69, 1.01]	0.64	[0.50, 0.81]
Battles within 250km during child's first year								
No (ref)								
Yes	1.25	[1.07, 1.47]	1.17	[0.87, 1.57]	0.96	[0.85, 1.08]	0.74	[0.63, 0.87]
Riots/protests within 50km during child's first year								
No (ref)								
Yes	0.97	[0.76, 1.23]	1.67	[1.10, 2.53]	0.93	[0.82, 1.05]	0.95	[0.79, 1.13]
Riots/protests within 100km during child's first year								
No (ref)								
Yes	1.15	[0.96, 1.38]	1.33	[0.97, 1.83]	0.95	[0.86, 1.06]	0.90	[0.77, 1.05]
Riots/protests within 250km during child's first year								
No (ref)								
Yes	1.35	[1.18, 1.55]	1.60	[1.22, 2.09]	0.99	[0.87, 1.11]	0.81	[0.65, 1.01]
Violence against civilians within 50km during child's first year								
No (ref)								
Yes	0.76	[0.60, 0.97]	1.26	[0.83, 1.91]	0.89	[0.77, 1.02]	0.81	[0.67, 0.98]
Violence against civilians within 100km during child's first year								
No (ref)								
Yes	0.93	[0.77, 1.11]	1.01	[0.74, 1.39]	0.89	[0.80, 0.99]	0.76	[0.65, 0.89]
Violence against civilians within 250km during child's first year								

No (ref)								
Yes	1.25	[1.09, 1.43]	1.15	[0.88, 1.50]	0.82	[0.75, 0.91]	0.72	[0.61, 0.84]

*Adjusted for wealthy households, urban/rural location, low birthweight, and child dietary diversity

Table 7A.10 Multivariate linear regression models of armed conflict count within 50, 100, and 250km during pregnancy and child height-for-age z-score in Madagascar and Zambia in Aim 3

	Madagascar Unadjusted		Madagascar Adjusted*		Zambia Unadjusted		Zambia Adjusted*	
Exposures	**Model 1**		**Model 2**		**Model 3**		**Model 4**	
	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI
Conflicts within 50km during pregnancy								
	-0.071	(-0.107, -0.036)	-0.094	(0.158, -0.029)	0.021	(0.016, 0.025)	0.016	(0.010, 0.021)
Conflicts within 100km during pregnancy								
	-0.044	(-0.065, -0.022)	-0.038	(-0.074, -0.003)	0.019	(0.015, 0.023)	0.015	(0.010, 0.020)
Conflicts within 250km during pregnancy								
	-0.016	(-0.028, -0.005)	-0.003	(-0.021, 0.015)	0.011	(0.009, 0.013)	0.009	(0.006, 0.011)
Fatal conflicts within 50km during pregnancy								
	-0.196	(-0.366, -0.026)	-0.269	(-0.540, 0.001)	0.090	(0.051, 0.130)	0.085	(0.012, 0.158)
Fatal conflicts within 100km during pregnancy								
	-0.119	(-0.232, -0.006)	-0.157	(-0.360, -0.046)	0.082	(0.051, 0.114)	0.079	(0.021, 0.138)
Fatal conflicts within 250km during pregnancy								
	-0.041	(-0.101, 0.020)	-0.024	(-0.128, 0.079)	0.076	(0.059, 0.092)	0.066	(0.039, 0.093)
Battles within 50km during pregnancy								
	0.281	(-0.206, 0.768)	0.486	(-0.307, 1.279)	0.011	(-0.095, 0.117)	- 0.099	(-0.274, 0.076)
Battles within 100km during pregnancy								
	0.069	(-0.194, 0.331)	0.066	(-0.354, 0.485)	- 0.014	(-0.094, 0.065)	- 0.120	(-0.253, 0.014)
Battles within 250km during pregnancy								
	-0.111	(-0.266, 0.043)	-0.318	(-0.573, -0.063)	0.060	(0.010, 0.110)	0.017	(-0.065, 0.098)
Riots/protests within 50km during pregnancy								
	-0.069	(-0.124, -0.014)	-0.122	(-0.220, -0.024)	0.029	(0.022, 0.036)	0.023	(0.013, 0.033)
Riots/protests within 100km during pregnancy								
	-0.018	(-0.046, 0.010)	-0.011	(-0.056, 0.034)	0.027	(0.021, 0.033)	0.021	(0.012, 0.029)
Riots/protests within 250km during pregnancy								
	-0.003	(-0.018, 0.013)	0.009	(-0.015, 0.032)	0.017	(0.014, 0.020)	0.012	(0.008, 0.017)
Violence against civilians within 50km during pregnancy								
	-0.078	(-0.150, -0.005)	-0.089	(-0.210, 0.032)	0.077	(0.060, 0.094)	0.067	(0.045, 0.090)
Violence against civilians within 100km during pregnancy								

	-0.101	(-0.154, -0.048)	-0.100	(-0.193, -0.007)	0.074	(0.060, 0.089)	0.065	(0.045, 0.084)
Violence against civilians within 250km during pregnancy								
	-0.100	(-0.130, -0.071)	-0.077	(-0.132, -0.021)	0.040	(0.032, 0.047)	0.034	(0.024, 0.044)

*Adjusted for wealthy households, urban/rural location, low birthweight, and child dietary diversity

Table 7A.11 Multivariate linear regression models of armed conflict count within 50, 100, and 250km during a child's first year and child height-for-age z-score in Madagascar and Zambia in Aim 3

	Madagascar Unadjusted		Madagascar Adjusted*		Zambia Unadjusted		Zambia Adjusted*	
Exposures	**Model 1**		**Model 2**		**Model 3**		**Model 4**	
	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI
Conflicts within 50km during child's first year								
	-0.027	(-0.060, 0.007)	-0.063	(-0.123, -0.003)	0.009	(0.005, 0.013)	0.004	(-0.001, 0.010)
Conflicts within 100km during child's first year								
	-0.039	(-0.065, -0.014)	-0.062	(-0.109, -0.016)	0.005	(0.002, 0.008)	0.002	(-0.003, 0.006)
Conflicts within 250km during child's first year								
	-0.016	(-0.027, -0.005)	-0.011	(-0.032, 0.010)	0.003	(0.000, 0.005)	0.000	(-0.002, 0.003)
Fatal conflicts within 50km during child's first year								
	-0.100	(-0.240, 0.040)	-0.103	(-0.322, 0.117)	0.058	(0.019, 0.097)	0.028	(-0.475, 0.101)
Fatal conflicts within 100km during child's first year								
	-0.186	(-0.290, -0.081)	-0.138	(-0.331, 0.055)	0.030	(-0.000, 0.061)	-0.002	(-0.062, 0.059)
Fatal conflicts within 250km during child's first year								
	-0.893	(-0.145, -0.034)	0.041	(-0.063, 0.145)	0.020	(0.003, 0.036)	-0.003	(-0.031, 0.026)
Battles within 50km during child's first year								
	0.156	(-0.226, 0.539)	0.615	(-0.025, 1.255)	0.123	(0.033, 0.213)	0.154	(-0.051, 0.358)
Battles within 100km during child's first year								
	-0.066	(-0.300, 0.169)	0.583	(0.162, 1.000)	0.108	(0.034, 0.181)	0.165	(-0.010, 0.340)
Battles within 250km during child's first year								
	-0.174	(-0.310, -0.037)	-0.166	(-0.425, 0.093)	0.032	(-0.015, 0.080)	0.071	(-0.033, 0.174)
Riots/protests within 50km during child's first year								

	-0.009	(-0.061, 0.043)	-0.042	(-0.136, 0.051)	0.012	(0.005, 0.019)	0.006	(-0.004, 0.016)
Riots/protests within 100km during child's first year								
	-0.029	(-0.067, 0.009)	-0.036	(-0.105, 0.033)	0.007	(0.002, 0.012)	0.002	(-0.006, 0.010)
Riots/protests within 250km during child's first year								
	-0.014	(-0.029, 0.002)	0.000	(-0.028, 0,029)	0.004	(0.001, 0.007)	0.000	(-0.004, 0.005)
Violence against civilians within 50km during child's first year								
	-0.005	(-0.076, 0.067)	-0.149	(-0.270, -0.028)	0.030	(0.014, 0.047)	0.017	(-0.005, 0.039)
Violence against civilians within 100km during child's first year								
	-0.023	(-0.077, 0.031)	-0.130	(-0.223, -0.036)	0.021	(0.009, 0.034)	0.010	(-0.007, 0.028)
Violence against civilians within 250km during child's first year								
	-0.058	(-0.089, -0.028)	-0.105	(-0.166, -0.044)	0.012	(0.006, 0.019)	0.003	(-0.007, 0.013)

*Adjusted for wealthy households, urban/rural location, low birthweight, and child dietary diversity

Constructs and Variables

Aim 1: Maternal and child characteristics
Outcomes
Child Stunting Status
Height-for-age z-score value placed into two groups using one cut-point
0 = non-stunted (height-for-age above -2 z-scores)
1 = stunted (height-for-age less than or equal to -2 z-scores)

Child Height-for-Age Z-score
Continuous height-for-age z-score value based on WHO Growth Standards, which uses standard deviations from benchmark child age and sex

Predictors
Maternal short stature (< 145 cm tall)
0 = normal stature
1 = short stature

Maternal BMI Status
Ordinal BMI status used a continuously measured BMI score categorized into clinically significant categories:
1 = Underweight (BMI < 18.5)
2 = Normal (18.5 ≤ BMI < 25)
3 = Overweight (BMI ≥ 25)

Child sex
1 = male
2 = female

Covariates

Wealth quintile from DHS
1 = Poorest
2 = Poorer
3 = Middle
4 = Richer
5 = Richest

Low birthweight (under 2.5kg)
0 = no
1 = yes

Child dietary diversity score

A WHO dietary diversity score for infants and children continuous measure of dietary diversity score 0-7 (low to high), which includes the following 7 food groups:

a. Grains, roots and tubers
b. Legumes and nuts
c. Dairy products (milk, yogurt, cheese)
d. Flesh foods (meat, fish poultry, and liver/organ meats)
e. Eggs
f. Vitamin-A rich fruits and vegetables
g. Other fruits and vegetables

Child dietary diversity score
Classified whether child's WHO dietary diversity score was adequate or inadequate:

0 = adequate
1 = inadequate

Birth order
Continuous measure of child's birth order according to the mother

Aim 2: Sanitation and EED Risk Factors

Outcomes

Child Stunting Status

Height-for-age z-score value placed into two groups using one cut-point

0 = non-stunted (height-for-age above -2 z-scores)
1 = stunted (height-for-age less than or equal to -2 z-scores)

Child Height-for-Age Z-score

Continuous height-for-age z-score value based on WHO Growth Standards, which uses standard deviations from benchmark child age and sex

Predictors

Toilet type

Whether household had a flush toilet to piped sewer system or septic tank, which is the classification of highest quality source versus the rest as suggested by (Husseini et al. 2018):

0 = no (flush to pit latrine, flush to pit latrine, flush to somewhere else, flush to don't know where, ventilated improved pit latrine, pit latrine with or without slab, no facility/bush/field, composting toilet)
1 = yes (flush toilet to piped sewer system, flush toilet to septic tank)

DHS toilet types categorized by WHO and UNICEF's Joint Monitoring Programme as:

0 = unimproved facilities (no toilet facility, bush/field, bucket toilet, hanging toilet/, pit latrine without slab or open pit, flush toilet to somewhere else, flush to don't know where)
1 = improved facilities (composting toilet, ventilated improved pit latrine, pit latrine with washable slab, pit latrine with slab that cannot be washed, flush to piped sewer system, flush to septic tank, flush to pit latrine) (WHO and UNICEF 2017)

Drinking water source

Whether household had a piped drinking water into their dwelling, which is the highest quality source versus the rest as suggested by (Husseini et al. 2018):

0 = no (piped to yard/plot, public tap/standpipe, tube well or borehole, protected well, unprotected well, protected spring, unprotected spring, river/lake/ponds/stream/canal, rainwater, tanker truck, cart with water tank, bottled water)
1 = yes (piped into dwelling)

DHS water sources categorized by WHO and UNICEF's Joint Monitoring Programme as:

0 = unimproved sources (unprotected spring, unprotected dug well, cart with small tank/drum, tanker-truck, surface water, or bottled water)

1 = improved sources (piped water to dwelling, piped water to yard/plot, public tap or standpipe, tubewell or borehole, protected dug well, protected spring, or rainwater)

Floor materials (Florey and Taylor 2016)
Floor materials were grouped into three ordinal DHS categories:

0 = natural (earth, sand, clay, mud, and dung)
1 = rudimentary (tablets/wood planks, palm, bamboo mat, adobe)
2 = advanced/finished (parquet, polished wood, vinyl, asphalt, linoleum, cement, tiles, carpet, stone, bricks)

Sanitation animal ownership
Household ownership was assessed for the following animals: chicken, pigs, and/or cattle

0 = no ownership
1 = own at least one animal type

Shared toilet with other households

0 = no
1 = yes

Recent diarrhea
Whether child had had diarrhea in the last 14 days of DHS survey

0 = no
1 = yes

Treated drinking water
Whether households reported treating drinking water by each of the following methods: boiling, bleach, cloth straining, water filter, or solar

0 = no
1 = yes

Covariates

Child age category

0 = 0-23 months old
1 = 24-60 months old

Wealth quintile from DHS

1 = Poorest
2 = Poorer
3 = Middle
4 = Richer
5 = Richest

Wealthy household

0 = Richer and Richest DHS Wealth Quintile
1 = Middle, Poorer, or Poorest quintile

Maternal education

0 = No education
1 = Primary education
2 = Secondary education
3 = Higher education

Maternal secondary education attainment

0 = no
1 = yes

Urban/rural location

1 = urban
2 = rural

Aim 3: Conflict Exposures
Outcomes
Child Stunting Status

Height-for-age z-score value placed into two groups using one cut-point

0 = non-stunted (height-for-age above -2 z-scores)
1 = stunted (height-for-age less than or equal to -2 z-scores)

Child Height-for-Age Z-score

Continuous height-for-age z-score value based on WHO Growth Standards, which uses standard deviations from benchmark child age and sex

Exposures

Any conflict within buffer distance (50 km, 100 km, 250 km) during pregnancy:

0 = no conflicts
1 = at least one conflict

Conflict counts (50 km, 100 km, 250 km) during pregnancy:
Continuous measure of number of conflicts reported within DHS household buffer between 10-months prior and up until child's month of birth

Any conflict within buffer distance (50 km, 100 km, 250 km) during child's early life:
0 = no conflicts
1 = at least one conflict

Conflict counts (50 km, 100 km, 250 km) during child's early life:
Continuous measure of number of conflicts reported within DHS household buffer between child's month of birth and 24 months after

Conflict type
0 = non-violent transfer of territory
1 = remote violence
2 = violence against civilians
3 = riots/protests
4 = strategic development
5 = headquarters or base established
6 = battle with no territory change
7 = battle with non-state actor overtaking territory
8 = battle with government regaining territory

Fatalities
Continuous measure of reported fatalities for each conflict event

Covariates

Wealth quintile from DHS

1 = Poorest
2 = Poorer
3 = Middle
4 = Richer
5 = Richest

Wealthy household

0 = Richer and Richest DHS Wealth Quintile
1 = Middle, Poorer, or Poorest quintile

Maternal education

0 = No education
1 = Primary education
2 = Secondary education
3 = Higher education

Maternal secondary education attainment

0 = No
1 = Yes

Urban/rural location

1 = Urban
2 = Rural

Low birthweight

0 = No
1 = Yes

Number of household numbers

Continuous measure of total number of household members

Birth order

Continuous measure of child's birth order according to the mother

Child dietary diversity score

Classifying whether child's WHO dietary diversity score was adequate or inadequate:

0 = adequate (score 4 or higher)
1 = inadequate (score below 4)

Conflict Count Construction

DHS household clusters were joined with ACLED armed conflict events using geospatial data. These data were input imported into ArcGIS Desktop 10.5 as latitude and longitude coordinates under the standard projection system. In the ACLED database, armed conflict reports after 2009 in Madagascar and after 2014 in Zambia were excluded since the MDHS and ZDHS surveys began after those years, respectively.

Sensitivity analyses were performed to determine the distance between a household cluster and conflict occurrence and impact on child stunting. Little data had been published about national or neighborhood distance to major violence and anthropometric consequences in children born later. Distances for an appropriate buffer to examine the influence of conflict events was made considering the maximum length and width of each country. Madagascar has a maximum length of 1,580km and width of 560km while Zambia has a maximum length of 1,206km and width of 815km (Nations Encyclopedia 2017, Rasambainarivo and Ranaivoarivelo 2003). A buffer, or circular ring, around each GPS coordinate of a DHS cluster was created at 50km, 100km, and 250km for sensitivity testing. The buffer was created using the following ArcGIS sequence: Geoprocessing tools > Buffers > Input Features: DHS clusters > Distance XX km.

In the next step, DHS cluster buffers at different diameter distance were joined to ACLED conflict events. The number of events that fell within the DHS cluster buffer ring were counted. For example, if a cluster had 15 violent conflicts between 1997-2008 in Madagascar within a 50km diameter distance but 20 conflicts within a 100km diameter, then the data for 50km buffers would count 15 conflict events and 100km buffers would count 20 events. The element of time is ignored and simply treated as before the DHS survey was conducted. These analyses were specifically accomplished in ArcGIS 10.5 by spatially joining points of conflict data to DHS cluster buffer polygons through the following steps: selected each buffer > right click > Joins & Relates > Join > Join data from another layer based on spatial location > Choose layer to join “Conflict Events 1997-2008” > Each polygon is given a numeric attribute of sums > Count_ column output in attribute table. The attribute table is output into Excel (Arc Toolbox > Conversion Tools > Excel > Table to Excel) for use in SAS 9.4 statistical analyses.

A detailed dataset that specified each cluster identity to specific violent conflict observations was created for potential optional analyses. This would allow analytic separation of conflict dates and characteristics like fatality or conflict actors. To perform this dataset creation, a spatial join between the two datasets was performed to keep many records. This was specifically performed in ArcGIS through: Arc Toolbox > Analysis Tools > Overlay > Spatial Join > Target Features: Conflict Events 1997-2008 > Join Features: DHScluster50kbuffer > Join Operation: JOIN_ONE_TO_MANY > Keep All Target Features > Match Option: INTERSECT [Name output: Merge50k etc.]. There is a many-to-many merge where each DHS cluster ID and its buffer is appended to each matching conflict event within its cluster buffer boundary. Please see the Appendix Tables for the resulting descriptive statistics of conflict buffers.

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